

Technology & Policy Implications of Global Energy Scenarios that Stabilize Climate Change

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Interdisciplinary Program on
Environment and Resources
Stanford University
May 2, 2007

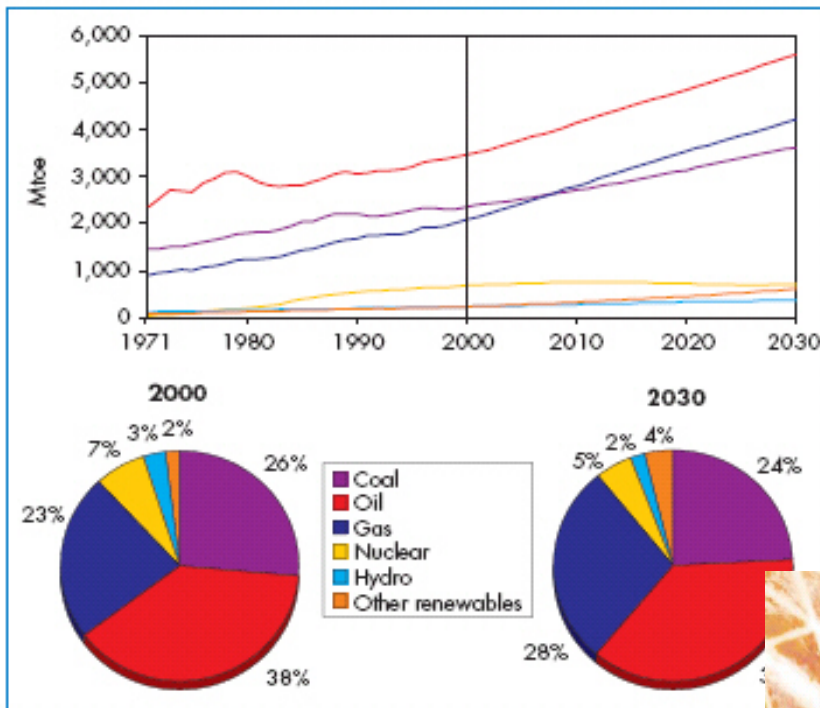
Decomposition of mitigation sources for a
rapid growth scenario with emissions constrained
to a doubling of CO₂ concentrations
above pre-industrial levels (A2r-4.5 W/m²)

Scenario by the Greenhouse Gas Initiative of the
International Institute for Applied Systems Analysis



WORLD ENERGY OUTLOOK 2002

Figure 2.1: World Primary Energy Demand



WORLD ENERGY INVESTMENT OUTLOOK

According to the WEO 2002, investment needed thru 2030 is **\$16 trillion...**

At least \$10 trillion is for fossil fuels and their delivery infrastructure...



INTERNATIONAL ENERGY AGENCY

WBGU

German Advisory Council on Global Change
(WBGU)

ENERGY TECHNOLOGY PERSPECTIVES



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



Climate Change 2007: The Physical Science Basis

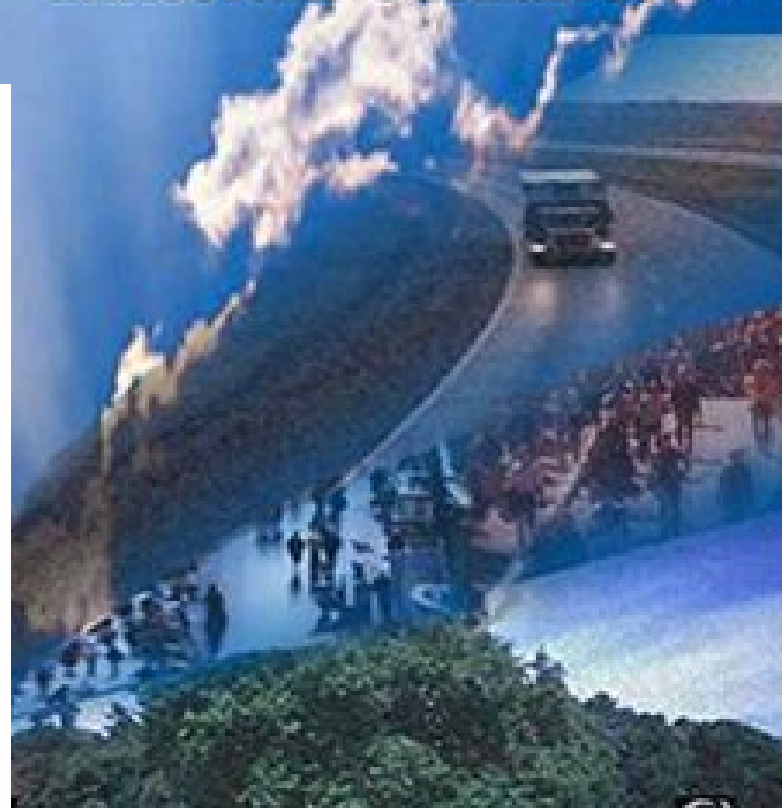
Summary for Policymakers

Contribution of Working Group I to the Fourth Assessment Report of the
Intergovernmental Panel on Climate Change



PEW CENTER
Global CLIMATE
CHANGE

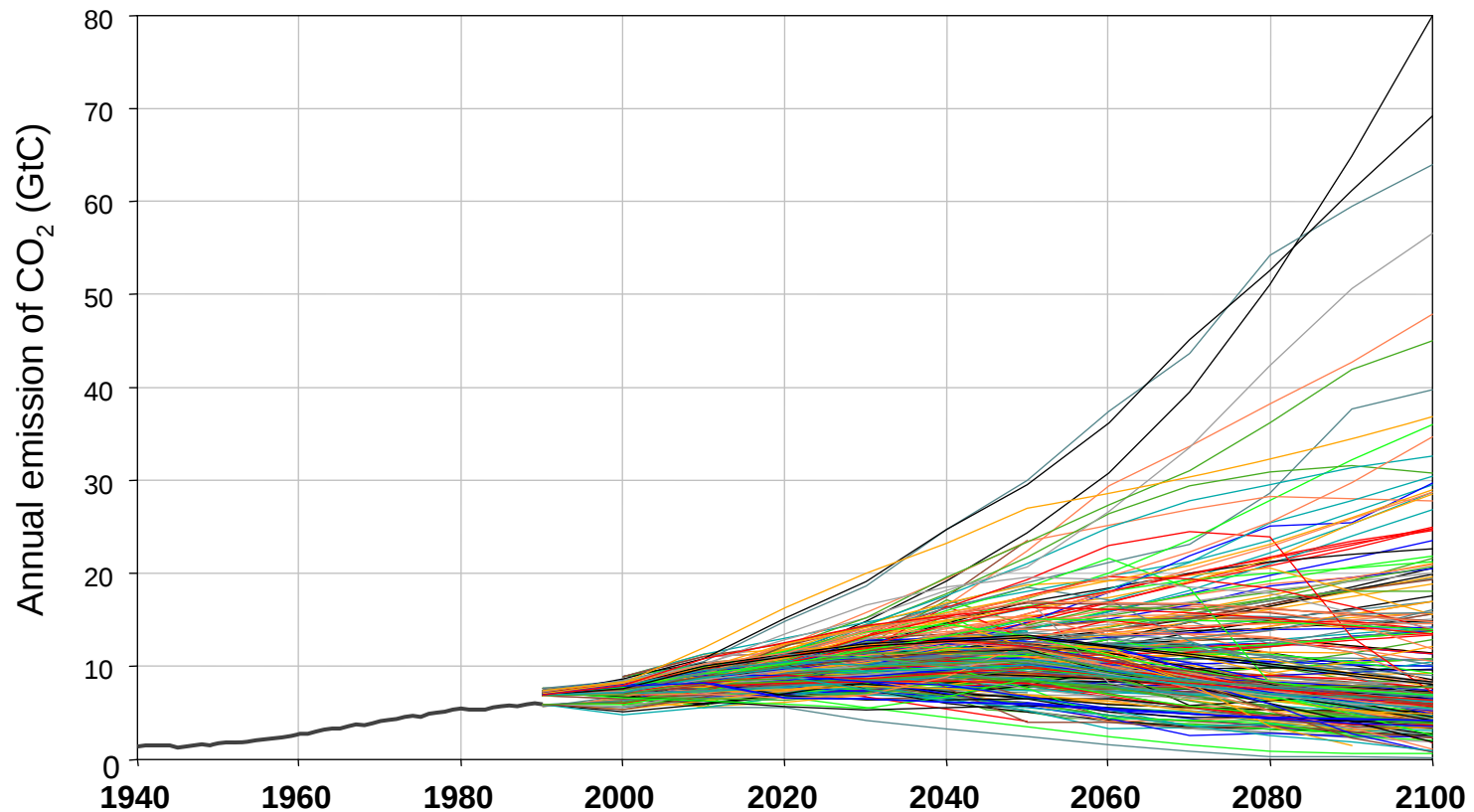
Special Report on Emissions Scenarios



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



Century-Scale Energy & Emissions Scenarios



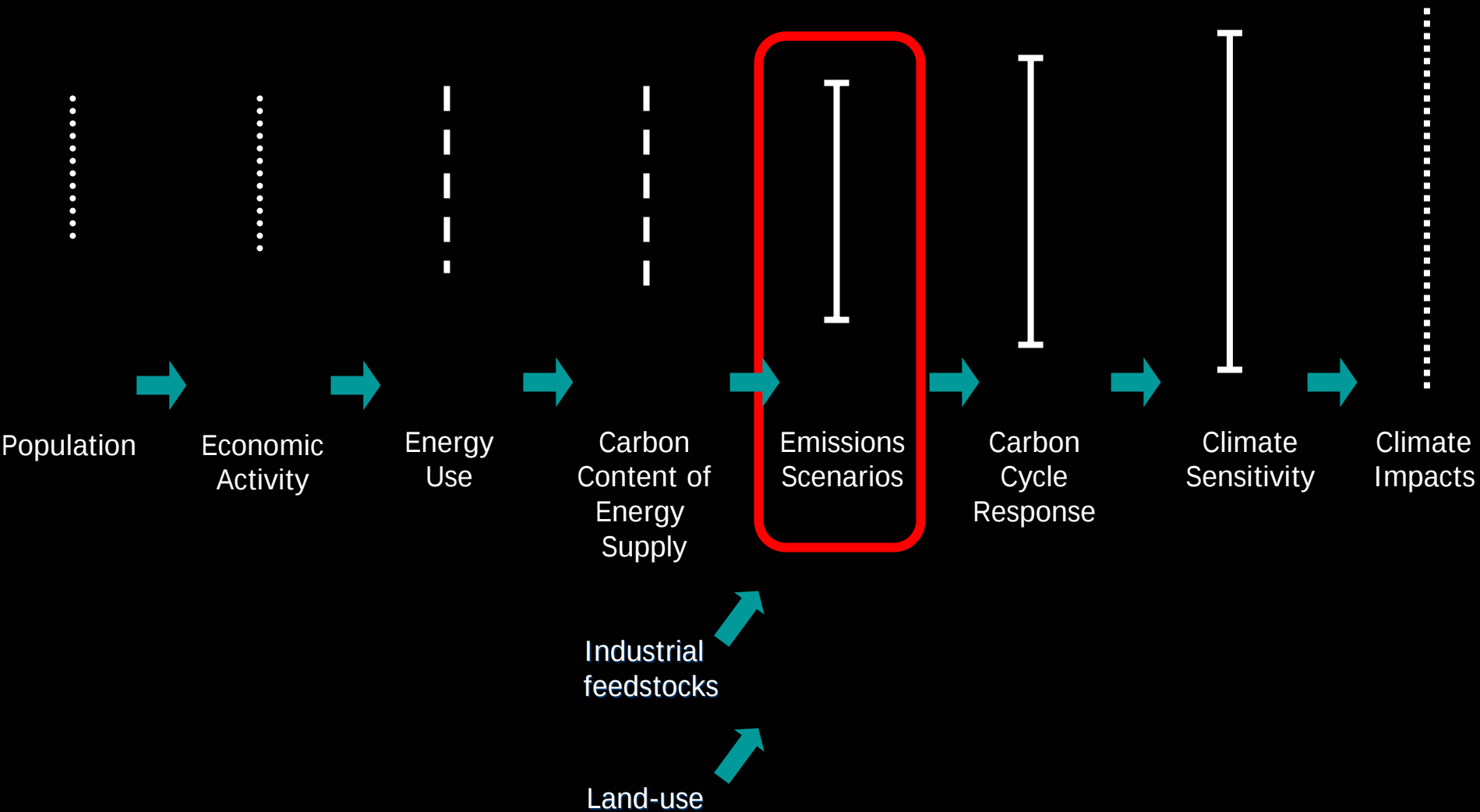
Data: National Institute for Environmental Studies, Japan; Graph: International Institute for Applied Systems Analysis

What do they mean?

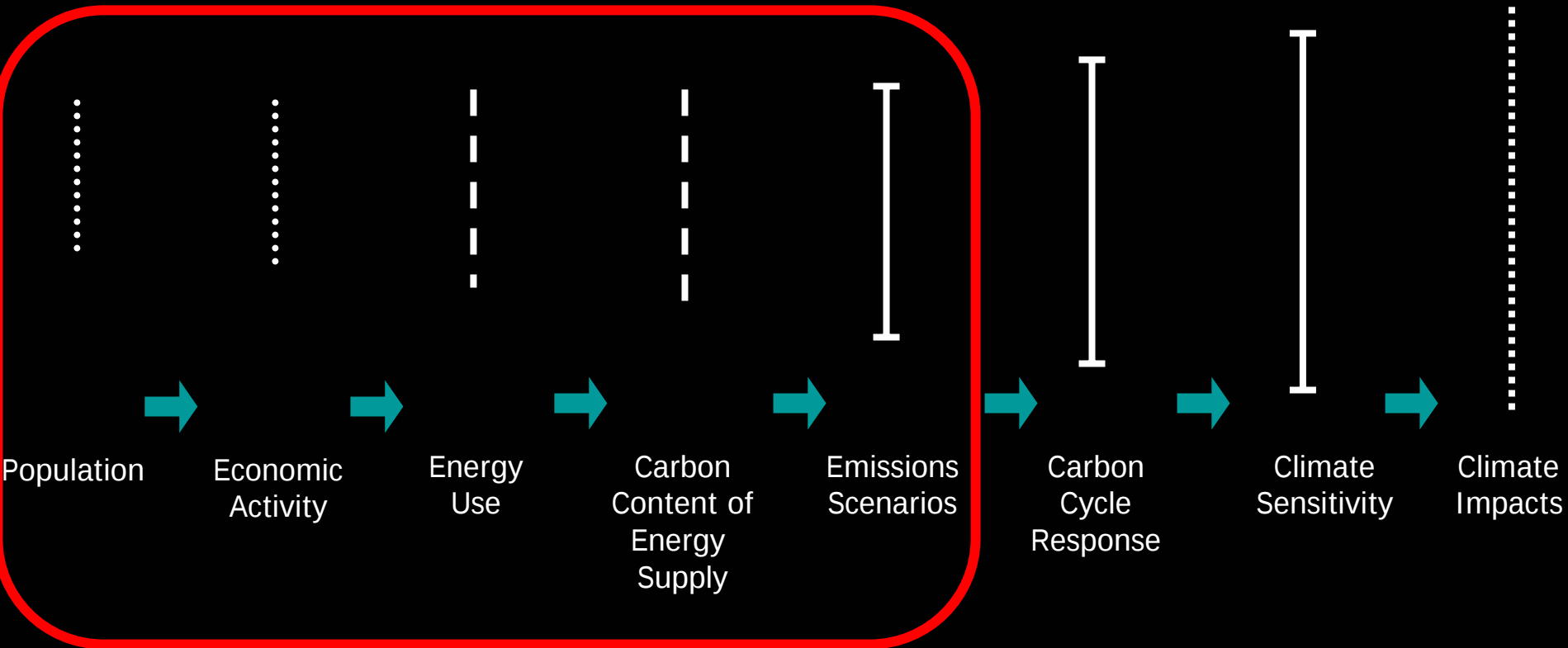
How do I know?

Does it make sense?

Simplified Line of Scenario Logic: Energy to Emissions



Simplified Line of Scenario Logic: Energy to Emissions



Energy scenario analysis is an essential tool
for exploring deep uncertainty
for the purpose of risk management

Exploring Energy Futures

- Constructing a common framework for interpretation
 - How do policy interventions affect key drivers of emissions?
 - What are the sources of mitigation in stabilization scenarios?
- Insights from analyzing several widely-cited energy scenarios
- What is the role of energy efficiency?
- Summary of Findings, and questions of your curiosity!

Decomposing Key Drivers of Carbon Emissions in Energy Scenarios

Population

Economic Welfare
(GDP per Capita)

Energy Intensity of
Economic Activity

Energy Supply
Loss Factor

P

$\times$

$\frac{GDP}{P}$

$\times$

$\frac{FE}{GDP}$

$\times$

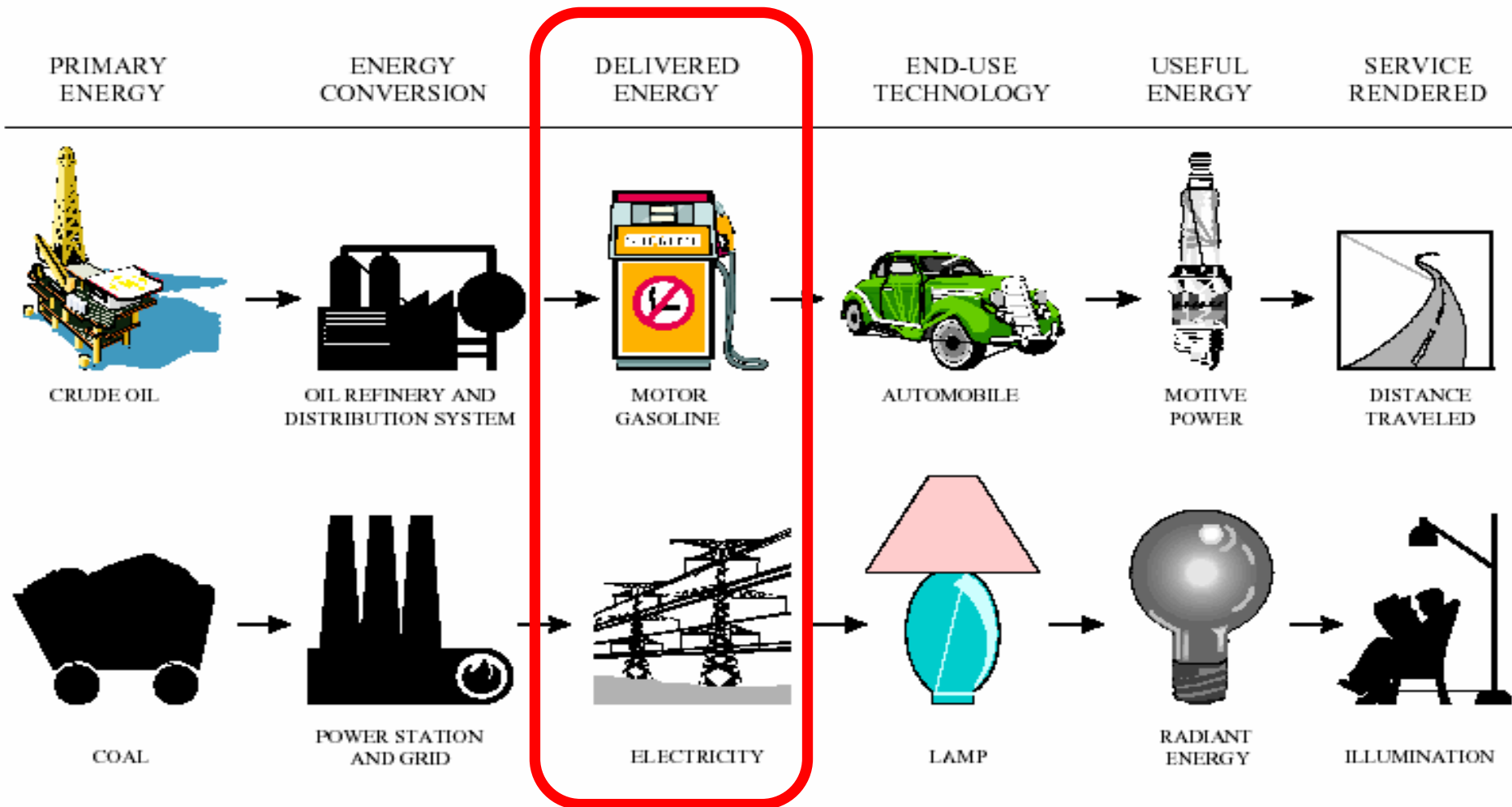
$\frac{PE}{FE}$



Primary Energy

Final Energy

Productive Use

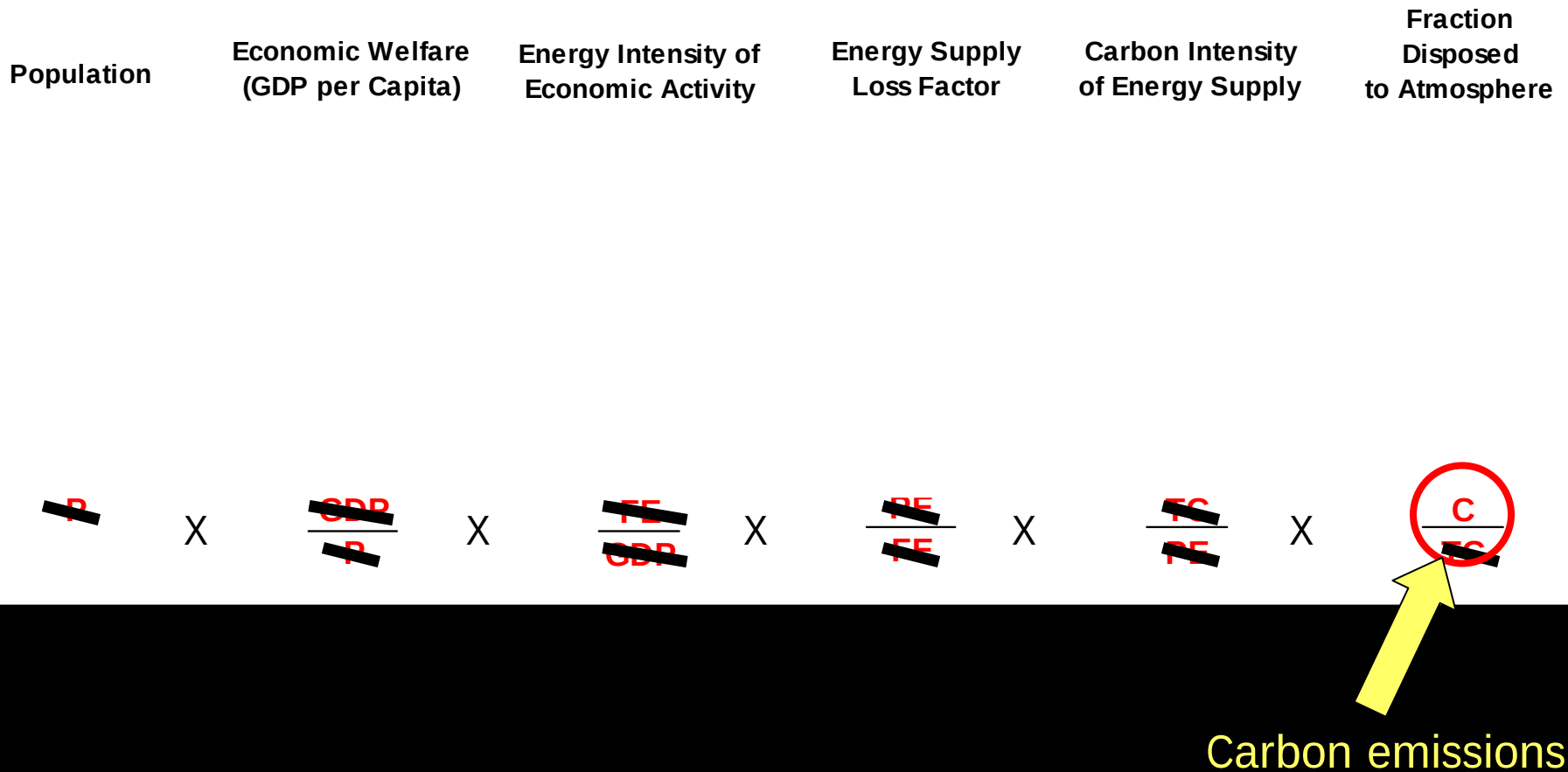


Decomposing Key Drivers of Carbon Emissions in Energy Scenarios

Population	Economic Welfare (GDP per Capita)	Energy Intensity of Economic Activity	Energy Supply Loss Factor	Carbon Intensity of Energy Supply	Fraction Disposed to Atmosphere
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$$P \times \frac{GDP}{P} \times \frac{FE}{GDP} \times \frac{PE}{FE} \times \frac{TC}{PE} \times \frac{C}{TC}$$

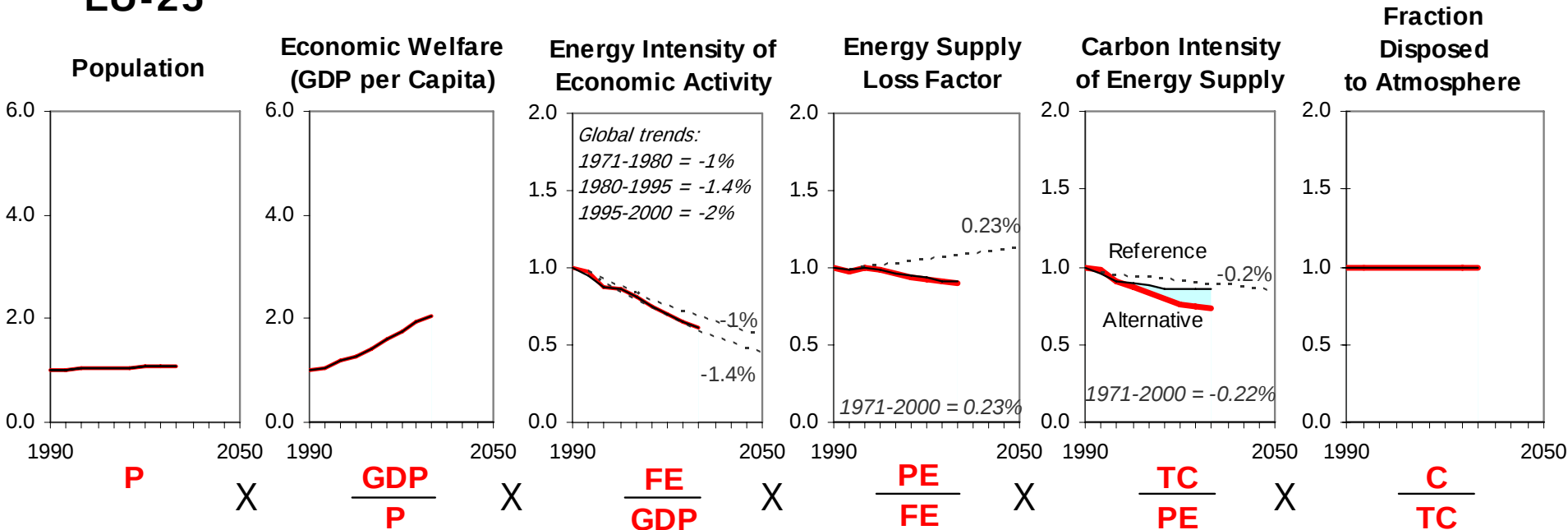
Decomposing Key Drivers of Carbon Emissions in Energy Scenarios



European Energy & Transportation: Renewables Only

Policy: 12% RPS for 2010 and 20% for 2020

EU-25

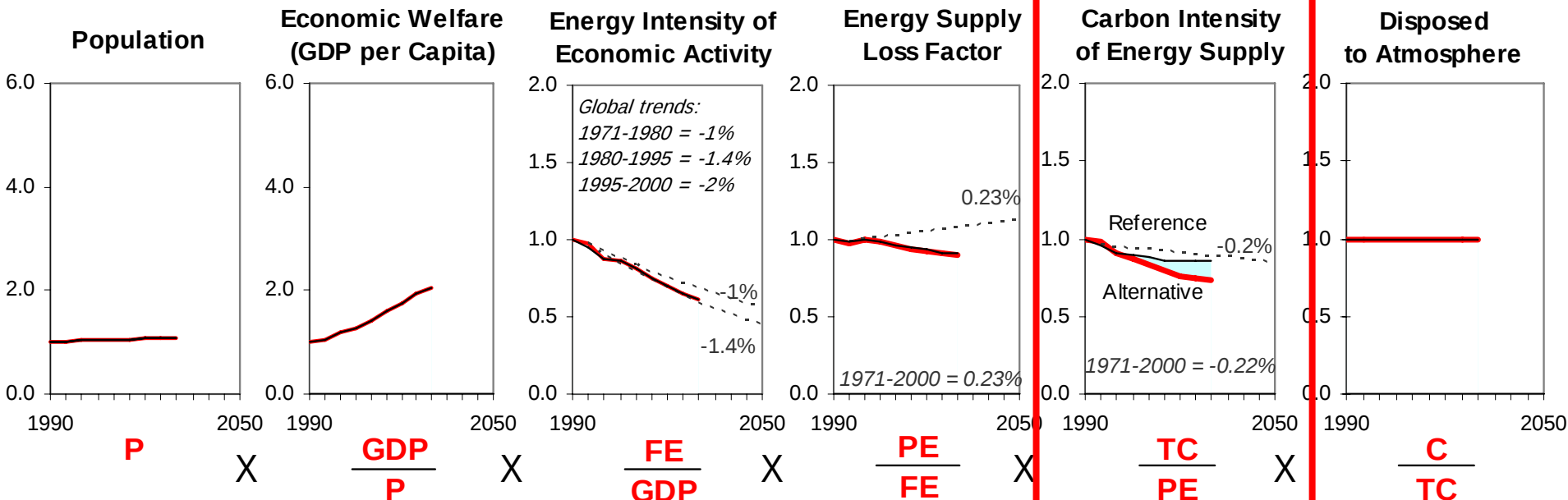


Indexed to 1990=1

European Energy & Transportation: Renewables Only

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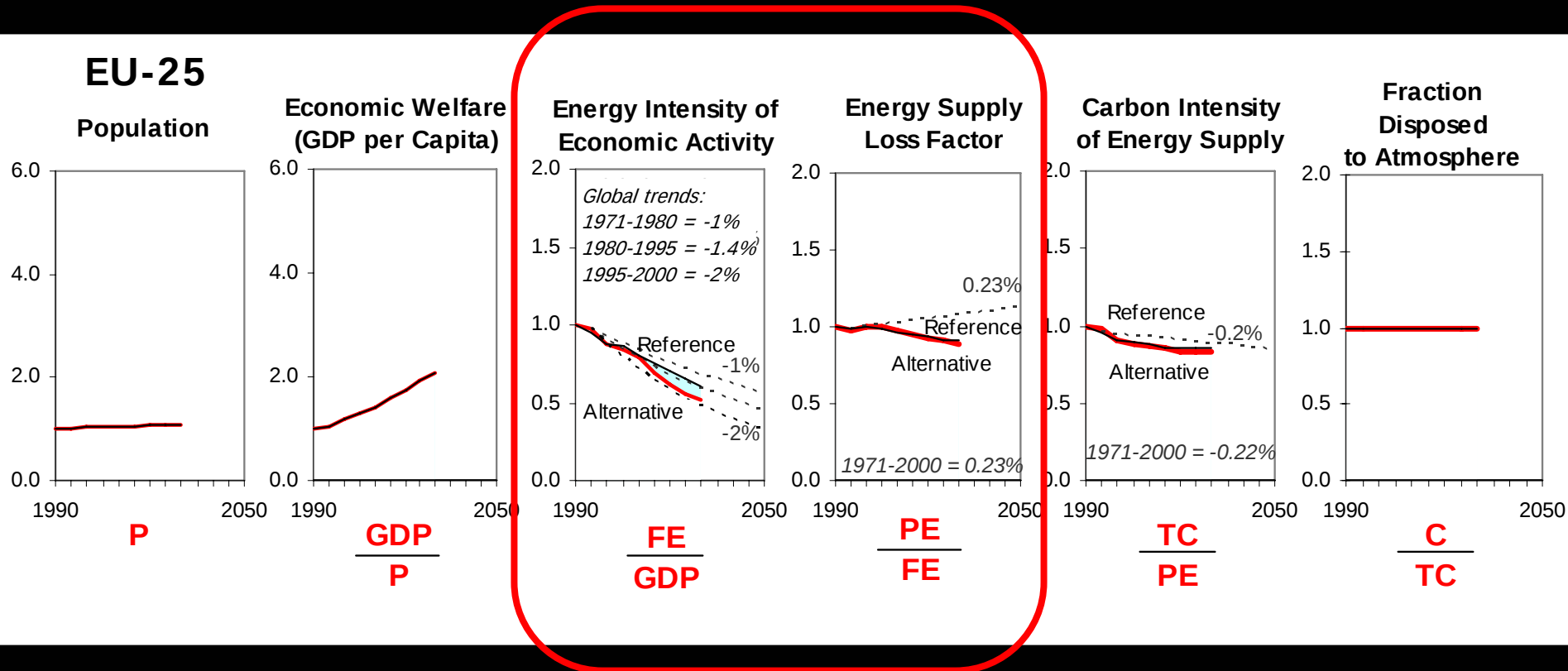
EU-25



Indexed to 1990=1

European Energy & Transportation: Efficiency Only

Policy: Several measures recommended by 6 different reports

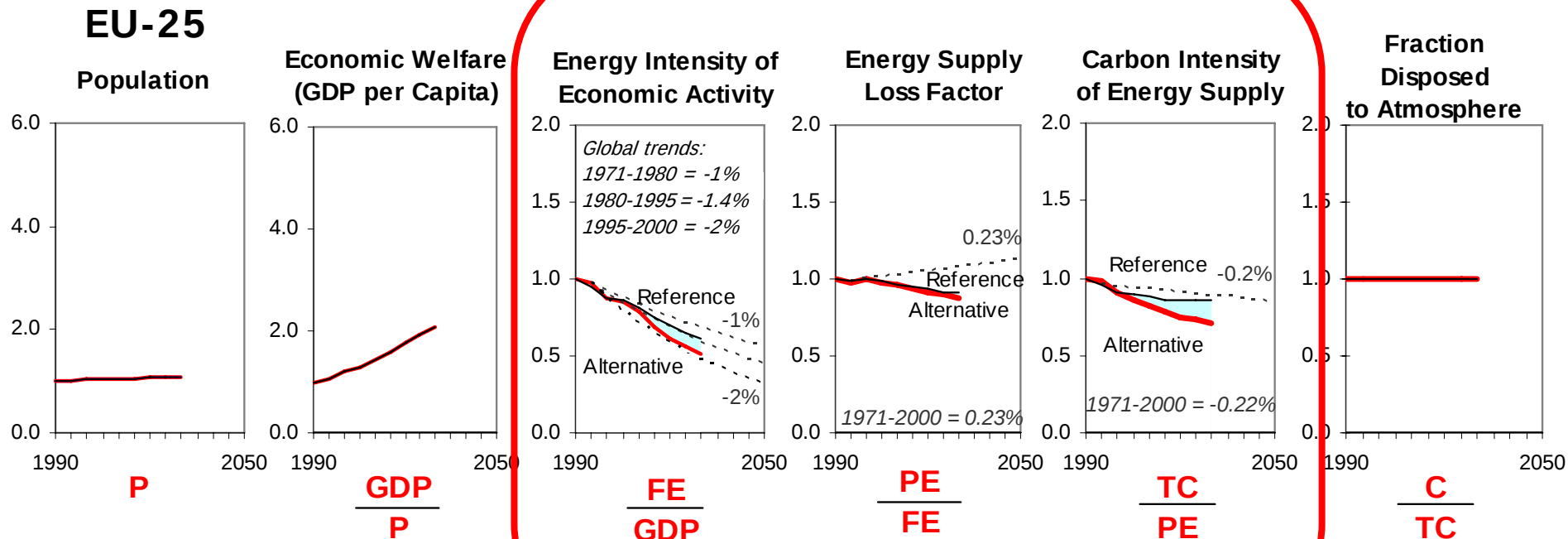


Demand-side (e.g. Buildings) Supply-side (e.g. Power plants)

Indexed to 1990=1

European Energy & Transportation:

Efficiency & Renewable Energy policies combined



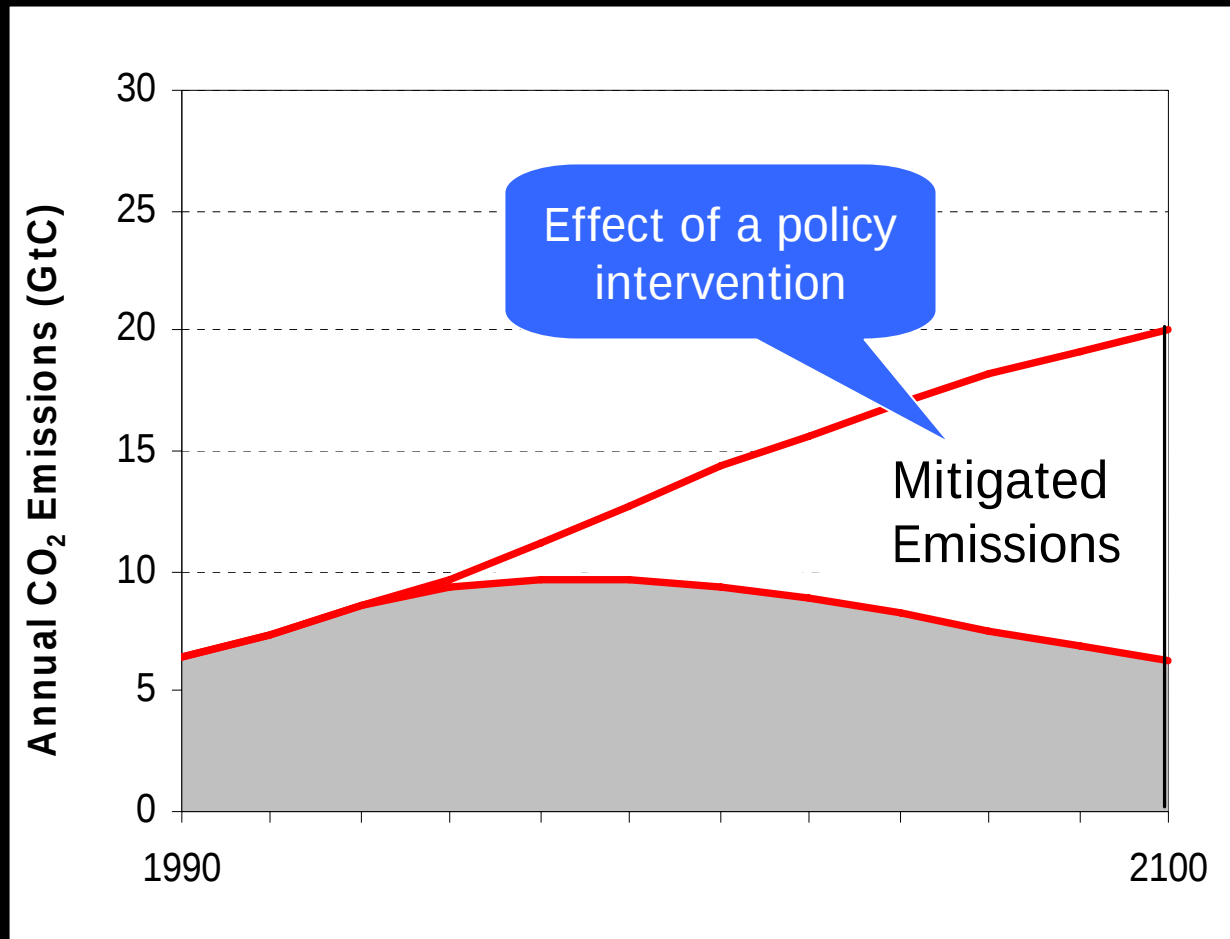
What does this mean for the portfolio of energy resources?

The second decomposition technique provides additional insight...

Exploring Energy Futures

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Basic emissions scenario analysis



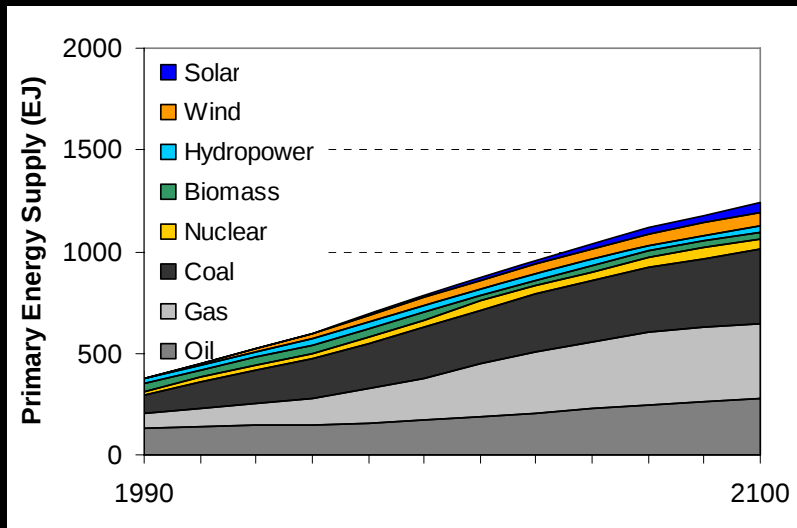
Emissions Profile
of a Possible
Future World

Path to
Stabilization

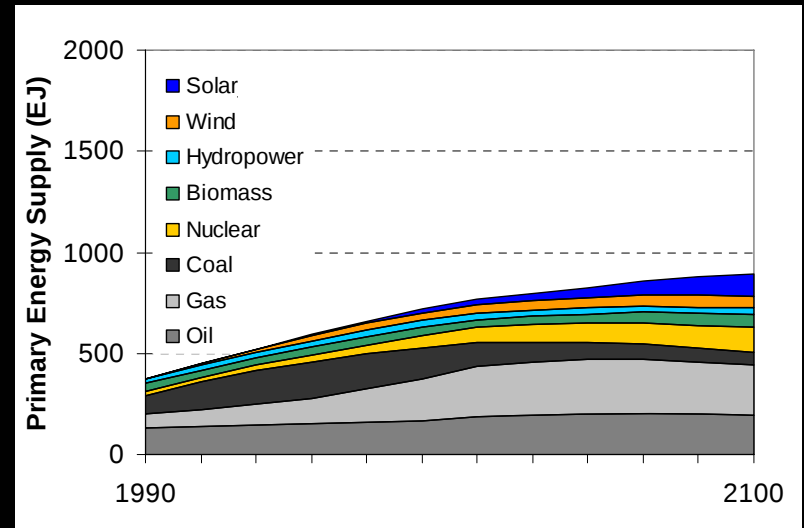
Changes to the Underlying Energy Sector

Primary Energy Resource Profile

Reference Case: “Before”



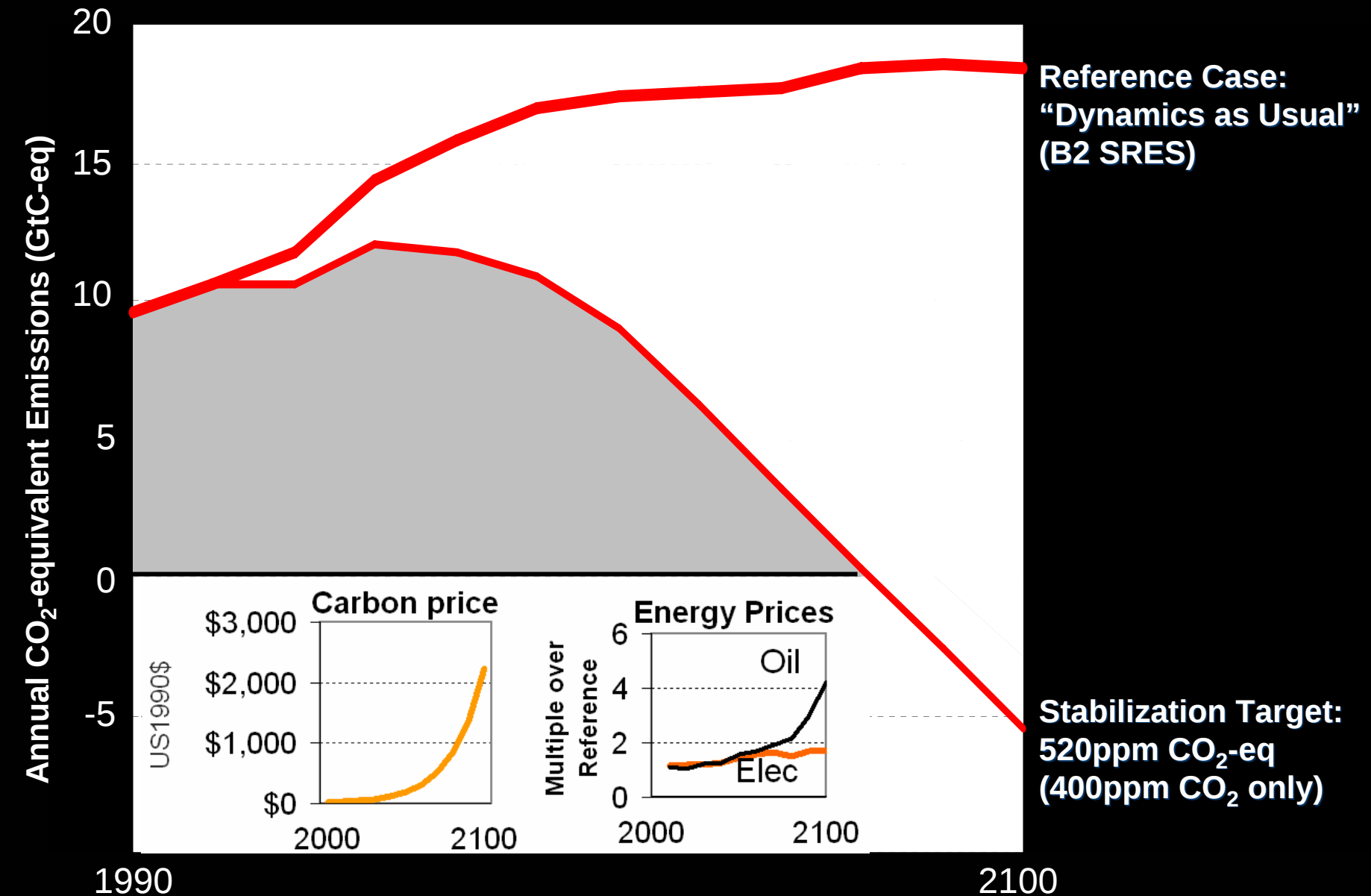
Mitigation Case: “After”



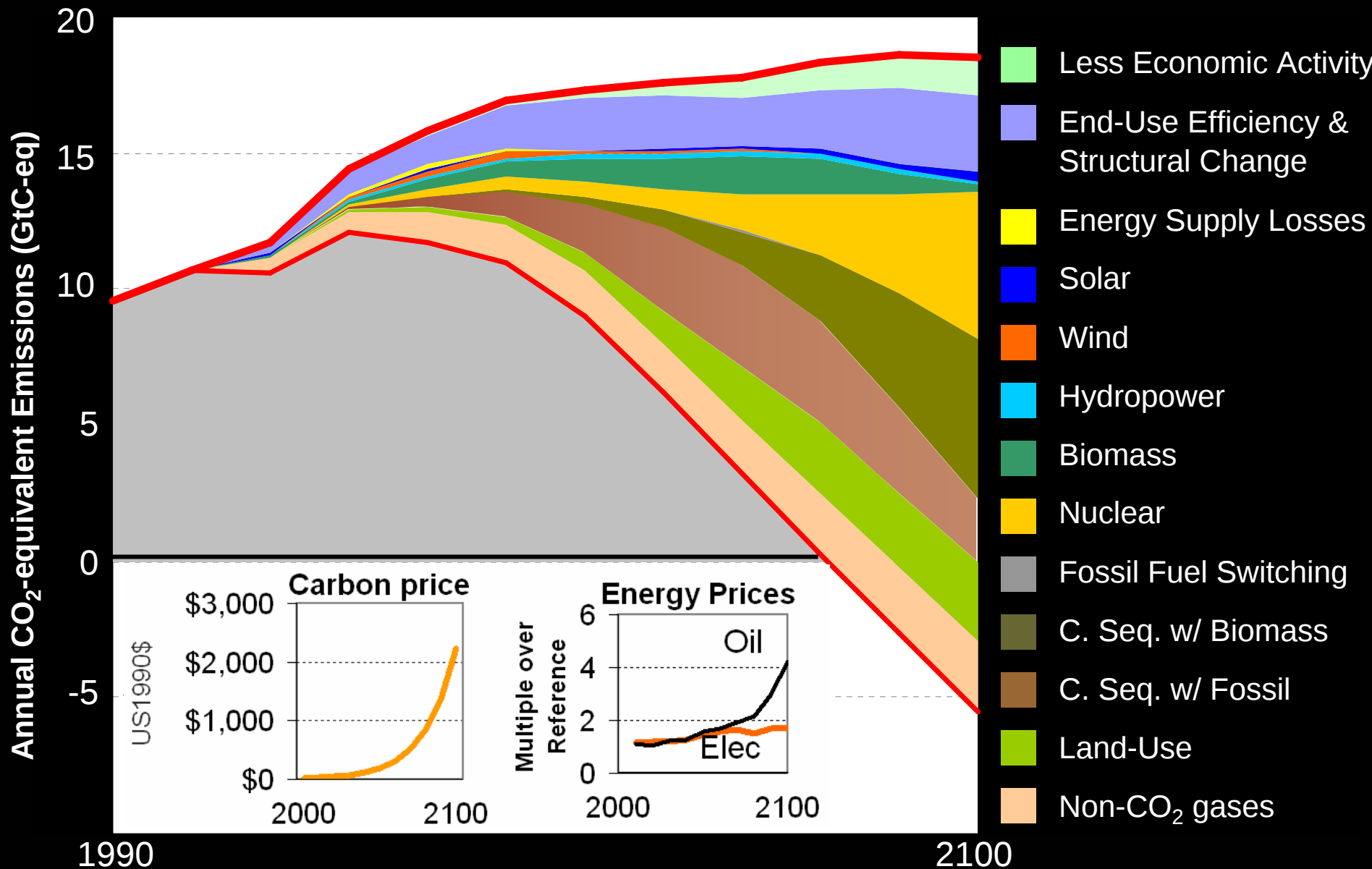
Moving beyond the familiar
for more insight...

- *Lower demand*
- *Less coal*
- *...a breakthrough technology*

Decomposing Sources of Mitigation

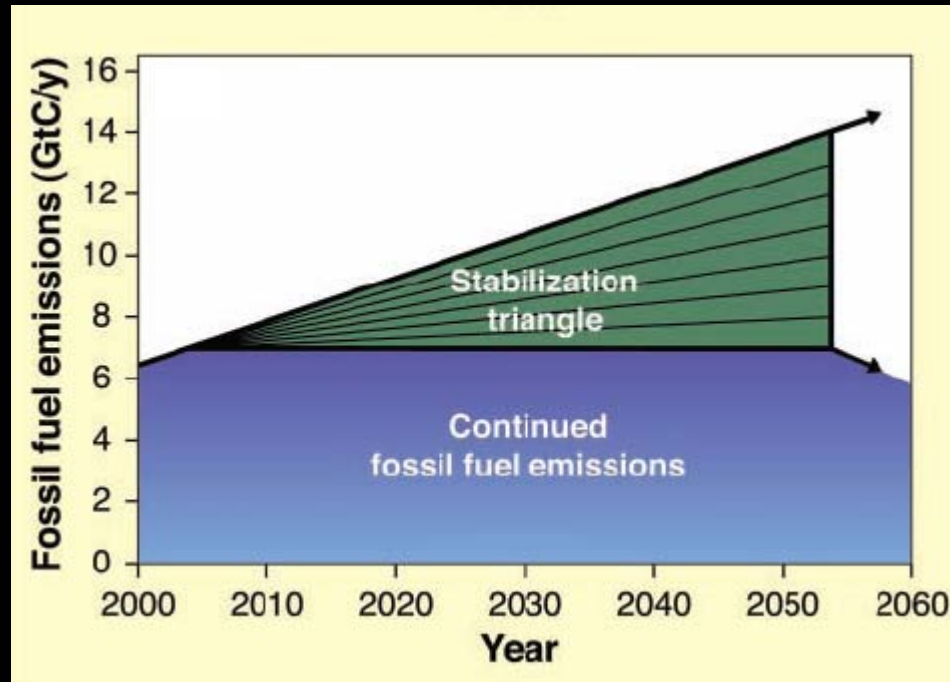


Decomposing Sources of Mitigation



Mid-range reference case (B2) limited to 520ppm CO₂-eq (GGI, 2006)

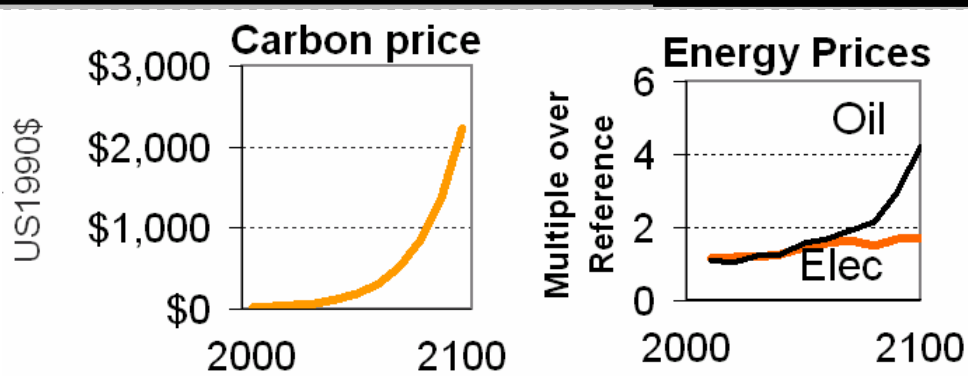
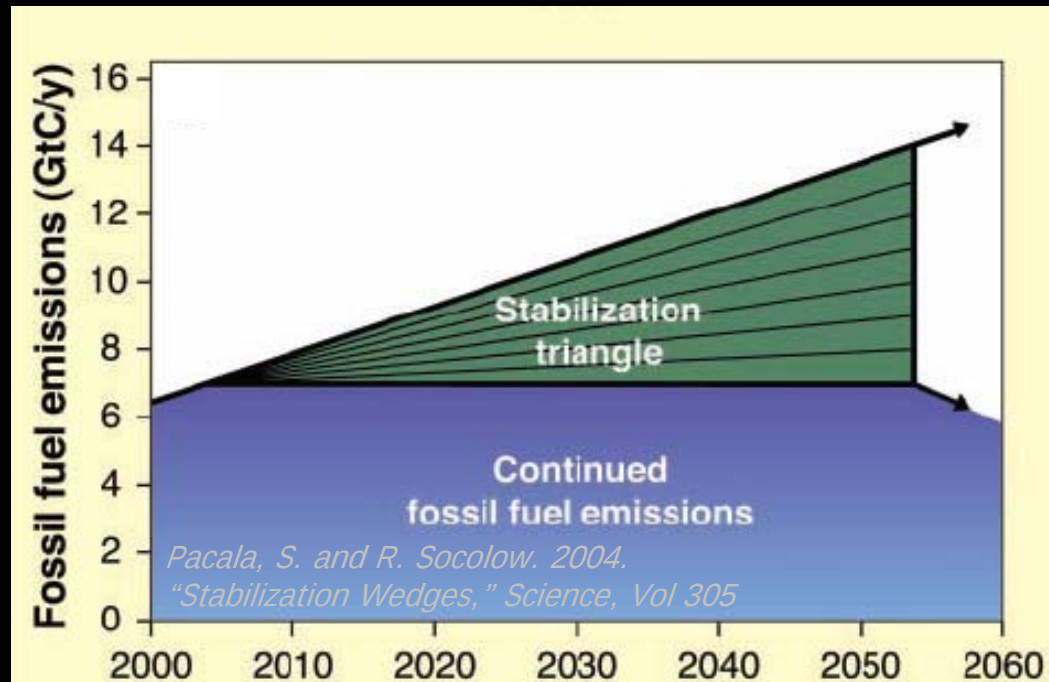
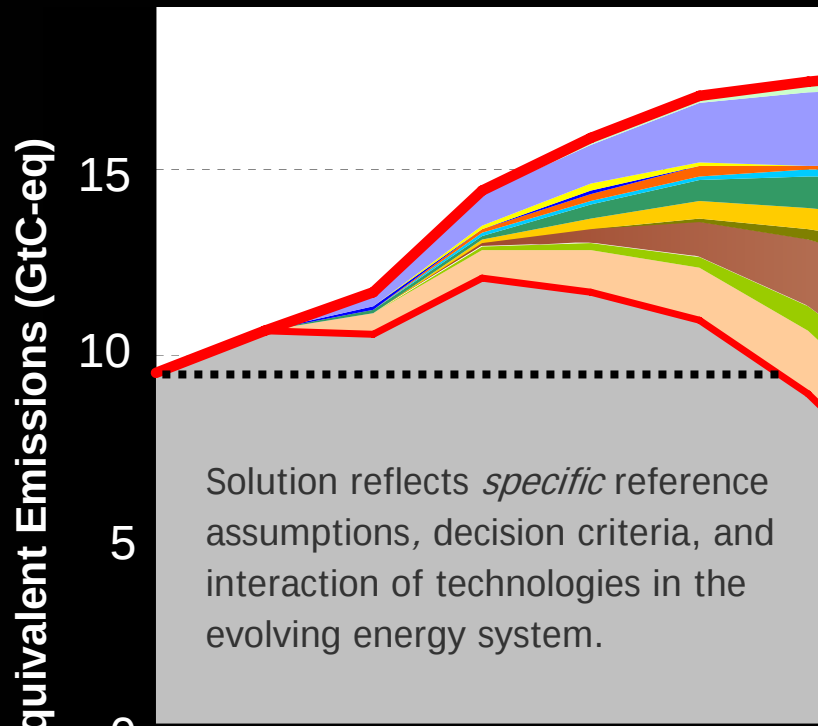
Comparison with “stabilization wedges” concept



Pacala, S. and R. Socolow. 2004. "Stabilization Wedges," Science, Vol 305

Presents fixed reference and stabilization paths,
then offers mix & match technologies
in units of a “stabilization wedge” (25 GtC).

Comparison with “stabilization wedges” concept



1990

2050

Mid-range reference case (B2) limited to 520ppm CO₂-eq (GGI, 2006)

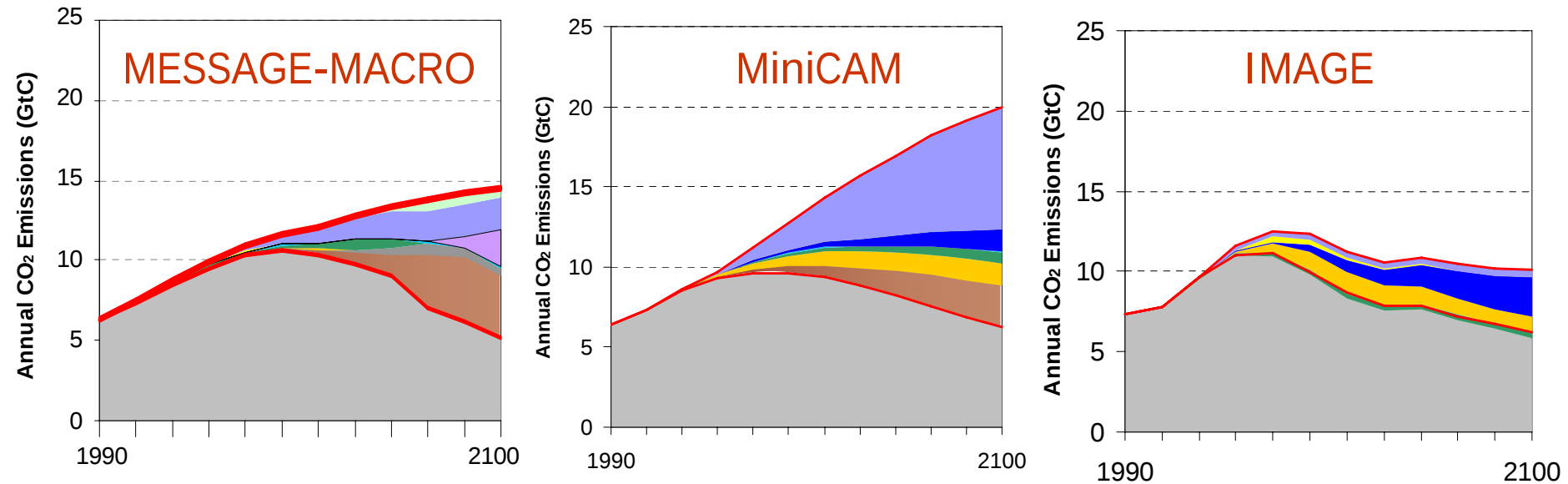
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Impact of model & modeler assumptions:

Same reference & stabilization target

Different models & technology assumptions



Reference: “Dynamics as Usual” (B2 SRES)

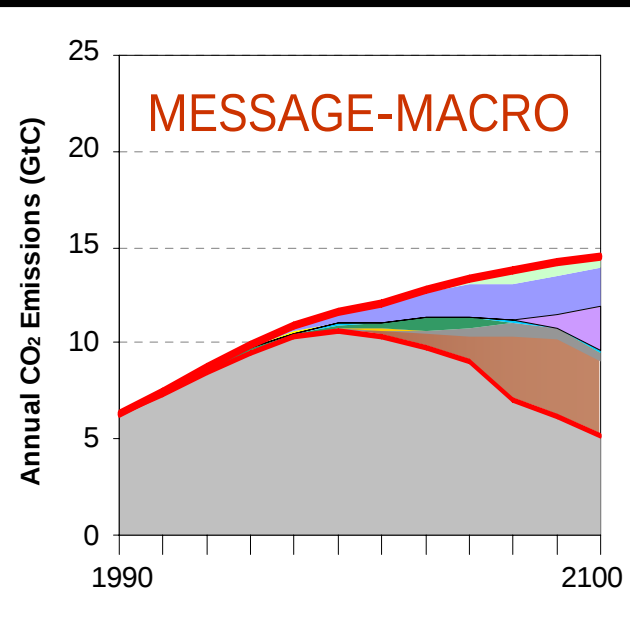
Mitigation Target: 550ppm CO₂ (doubling of pre-industrial levels)

Study: Energy Modeling Forum, Study #19

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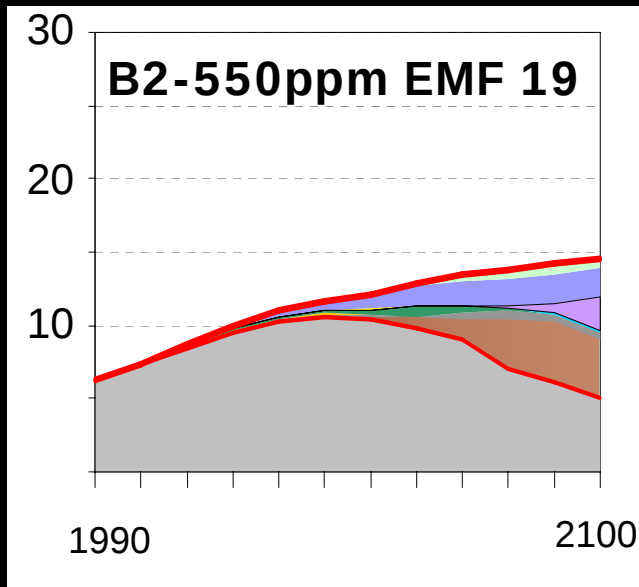
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Impact of Technology Assumptions:

Same Model (MESSAGE-MACRO, 1998-2004)

Different Reference cases & Stabilization targets

Annual CO₂ Emissions (GtC)

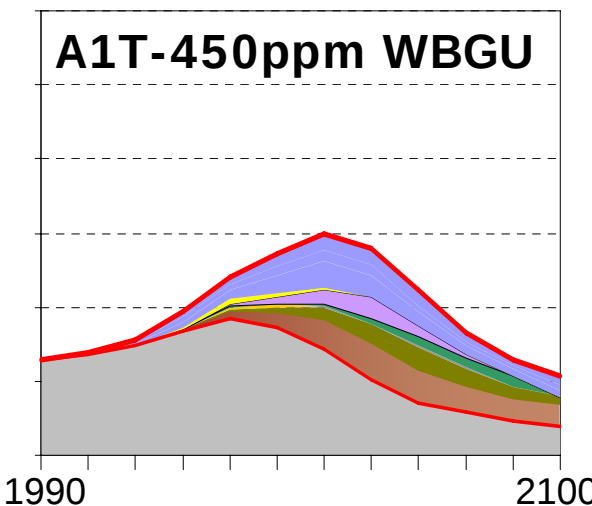
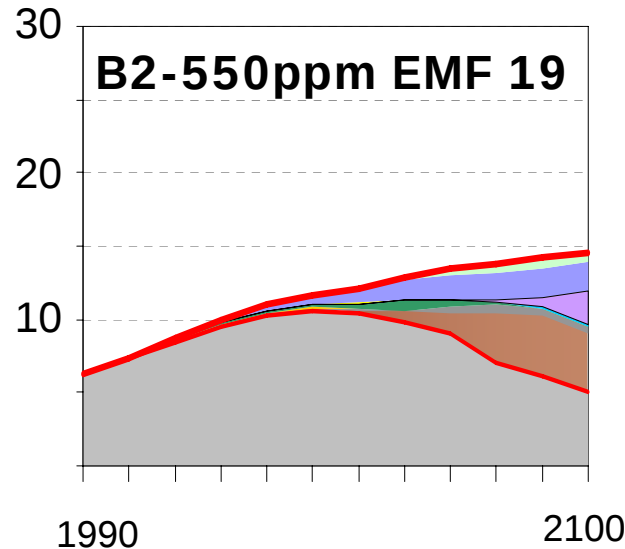
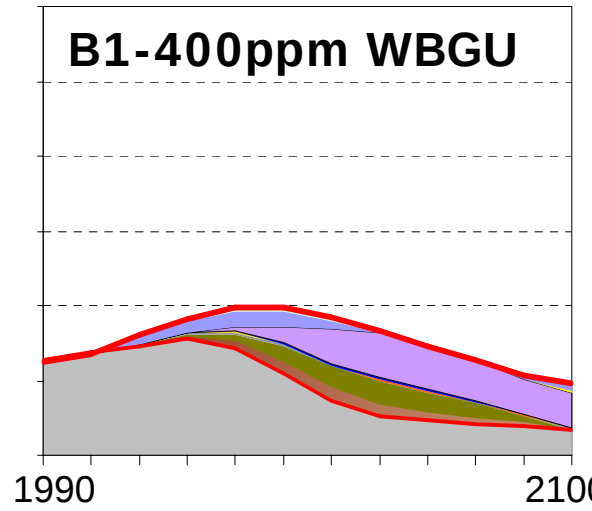
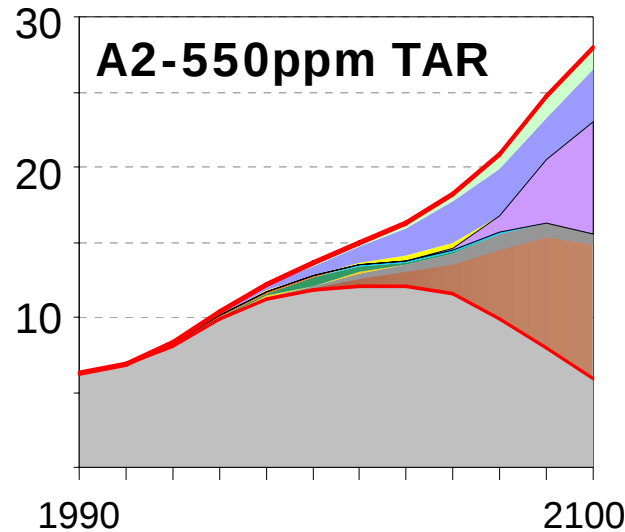


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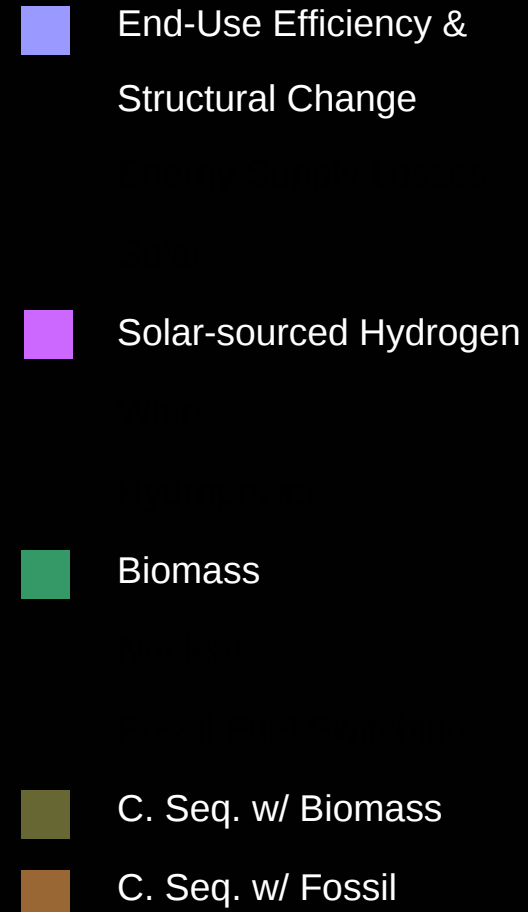
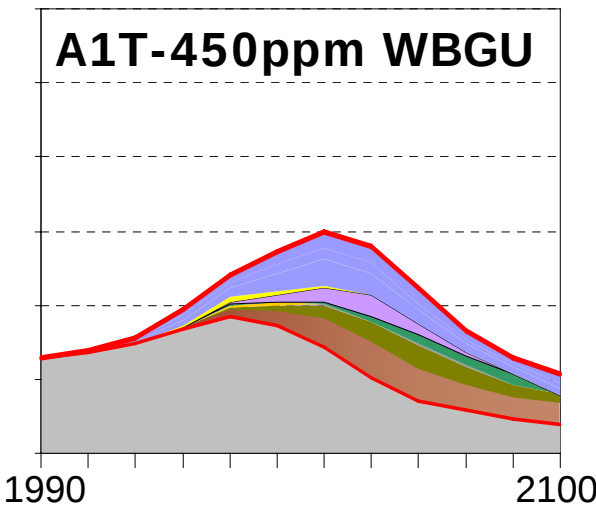
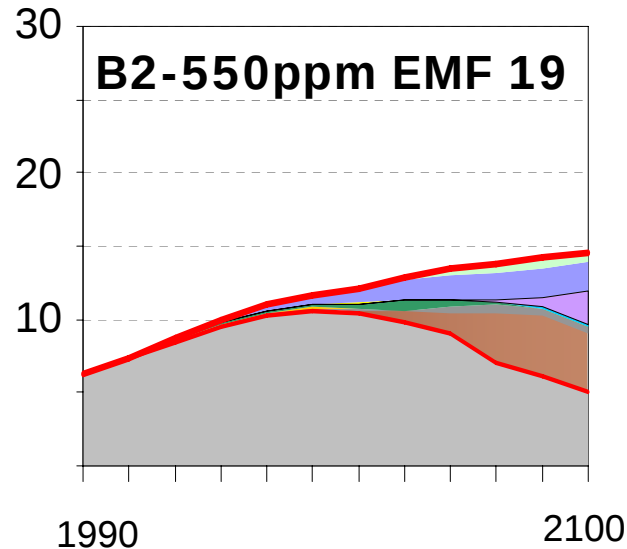
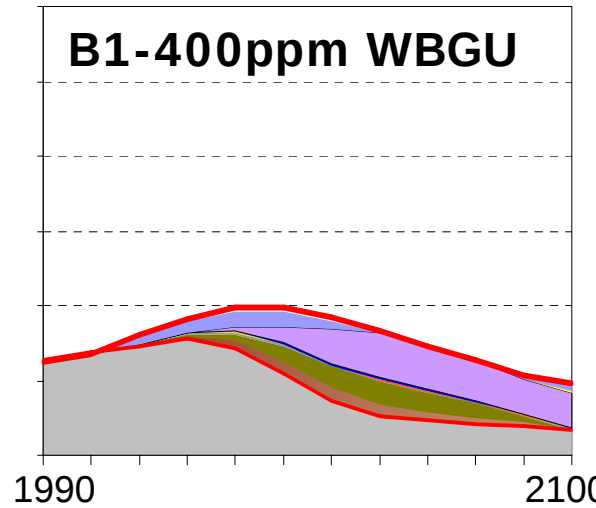
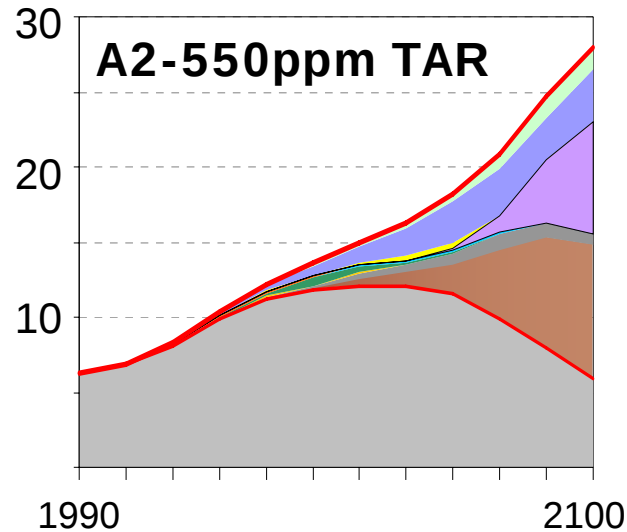


Impact of Technology Assumptions:

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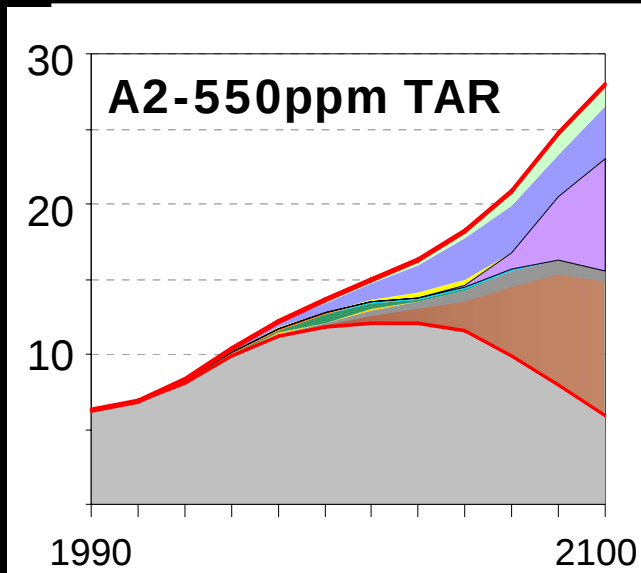


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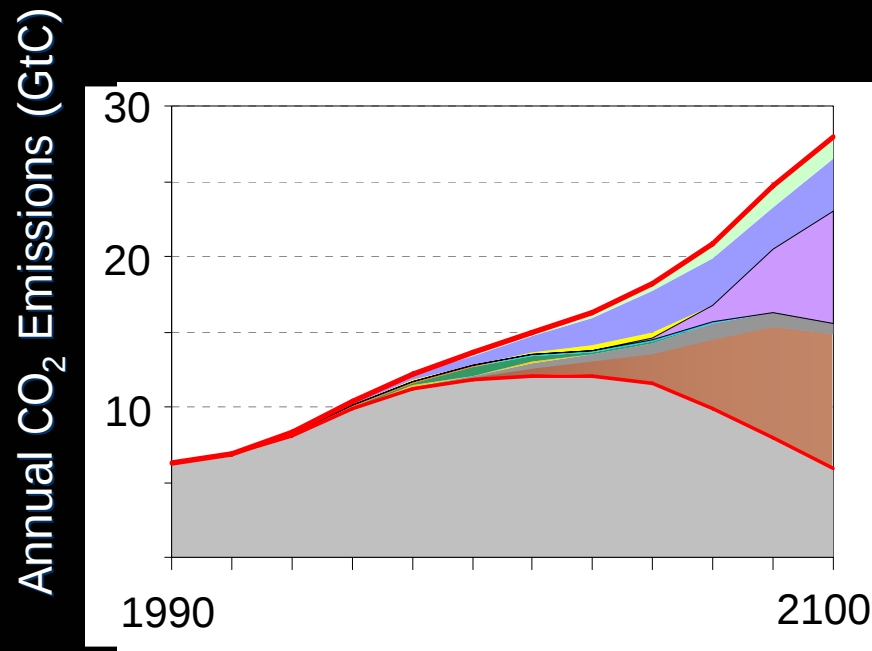
Different Reference cases & Stabilization targets

Annual CO₂ Emissions (GtC)



Impact of technology assumptions:

Similar high growth reference case and stabilization target from the same model with different technology assumptions



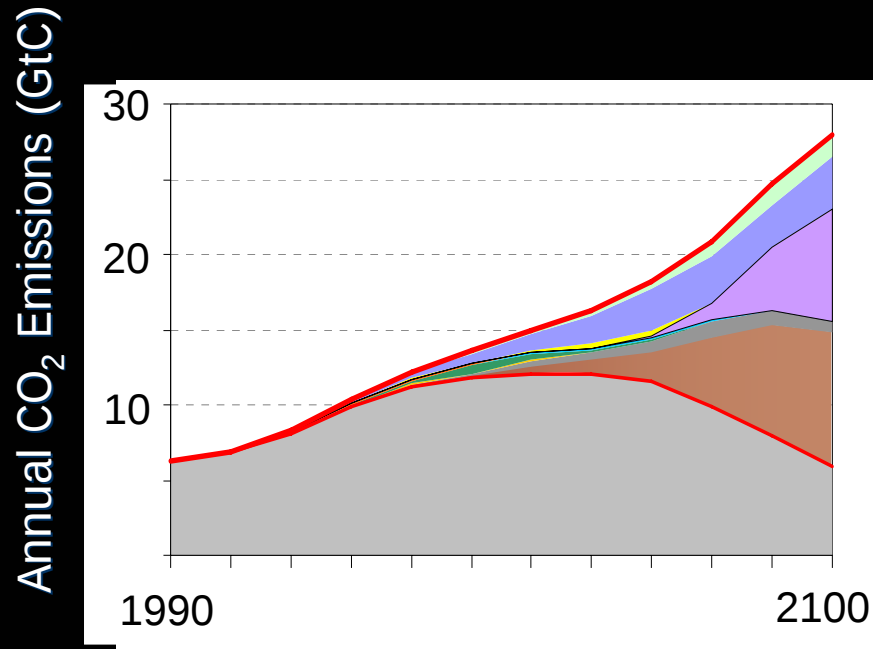
Reference: A2 (SRES)

Target: 550 ppm CO₂ only

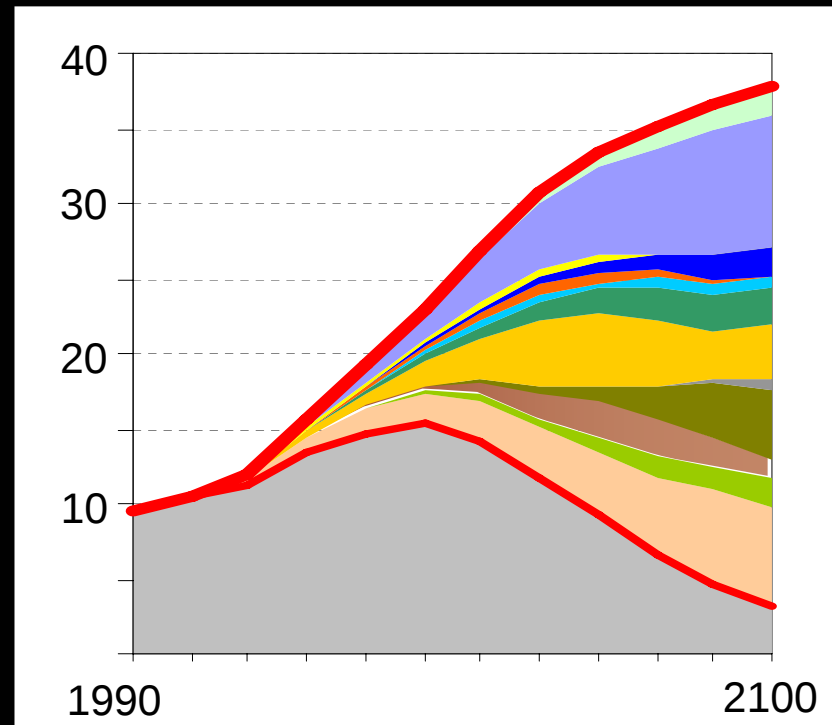
Model: MESSAGE-MACRO

Impact of technology assumptions:

Similar high growth reference case and stabilization target from the same model with different technology assumptions



Reference: A2 (SRES)
Target: 550 ppm **CO₂ only**
Model: MESSAGE-MACRO

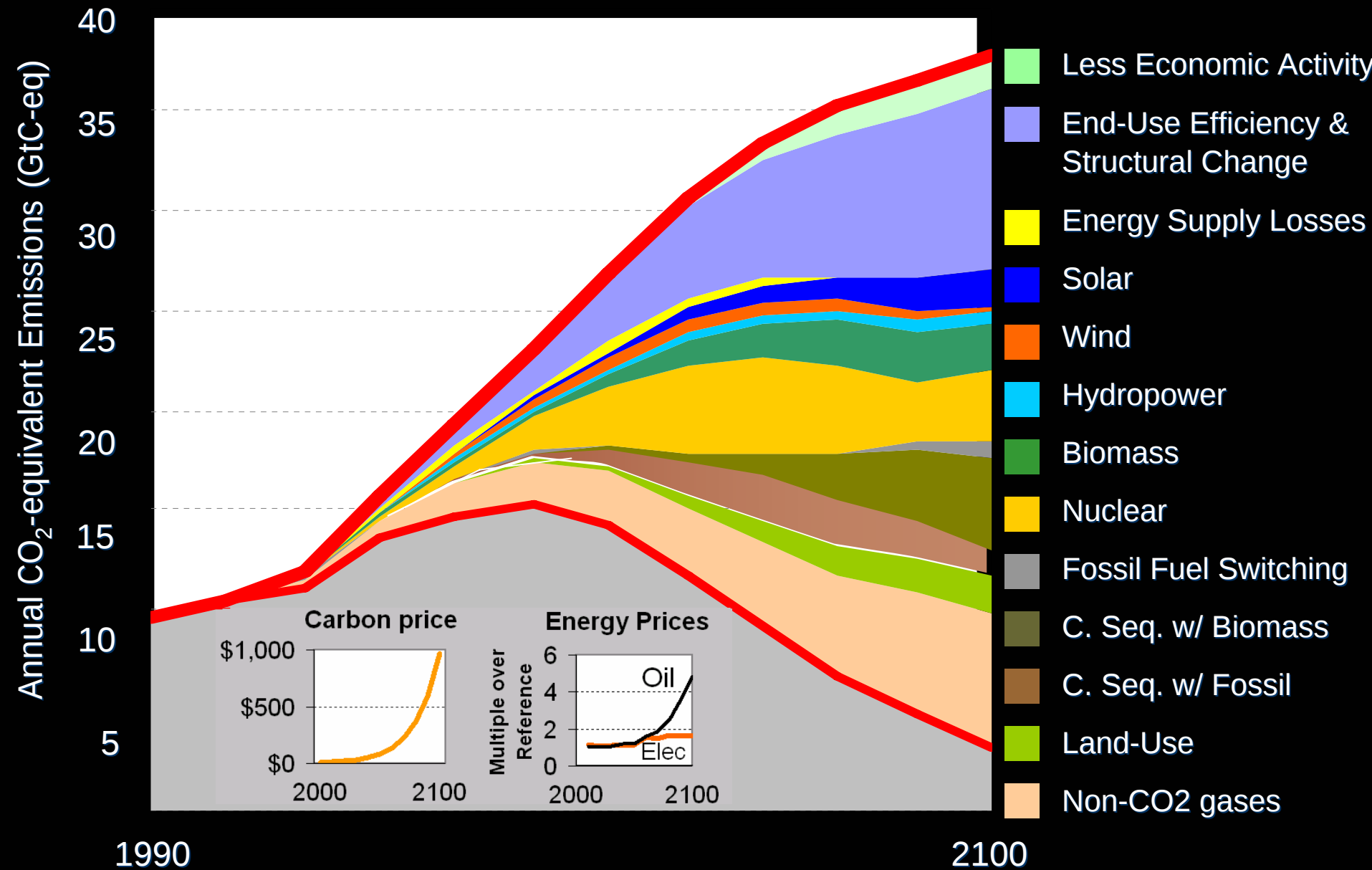


Reference: A2 (SRES) multi-gas
Target: 4.5 W/m² (670ppm **CO₂-eq**) multi-gas
Model: MESSAGE-MACRO

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Examining the Role of Efficiency



High growth reference case (A2) limited to 670ppm CO₂-eq (MSG-MACRO, GGI, 2006)

Examining the Role of Efficiency

Economic Welfare
(GDP per Capita)

$$\frac{\text{GDP}}{P}$$

Energy Intensity of
Economic Activity

$$\frac{FE}{GDP}$$

Energy Supply
Loss Factor

$$\frac{PE}{FE}$$

Carbon Intensity
of Energy Supply

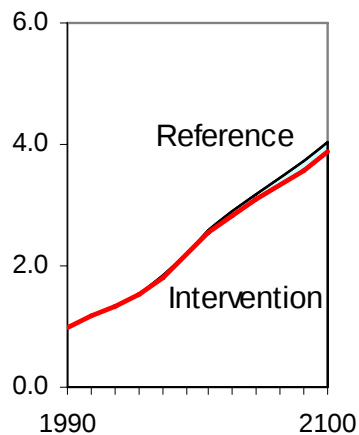
$$\frac{TC}{PE}$$

Fraction
Disposed
to Atmosphere

$$\frac{C}{TC}$$

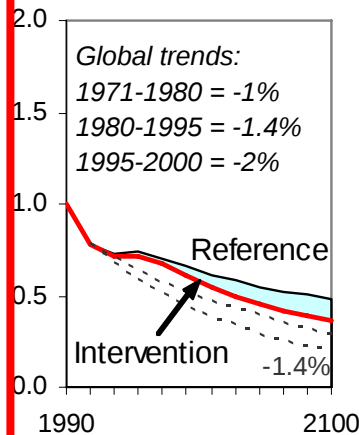
Examining the Role of Efficiency

**Economic Welfare
(GDP per Capita)**



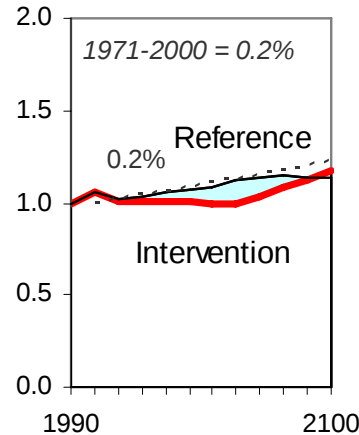
GDP
P

**Energy Intensity of
Economic Activity**



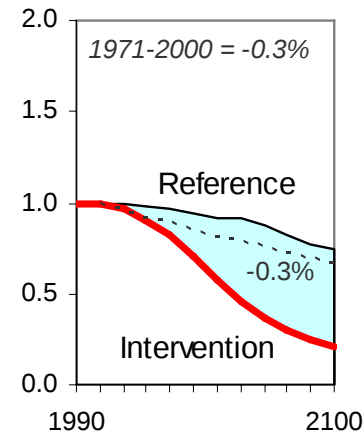
FE
GDP

**Energy Supply
Loss Factor**



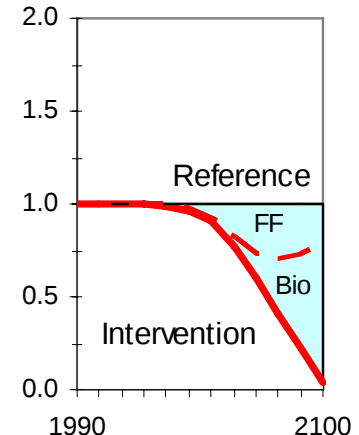
PE
FE

**Carbon Intensity
of Energy Supply**



TC
PE

**Fraction
Disposed
to Atmosphere**



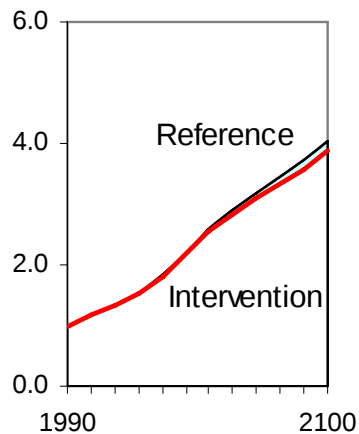
C
TC

Indexed to 1990=1

High growth reference case (A2) limited to 670ppm CO₂-eq (MSG-MACRO, GGI, 2006)

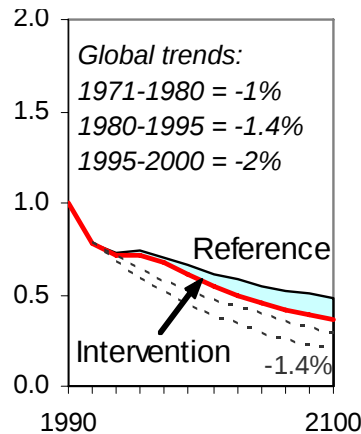
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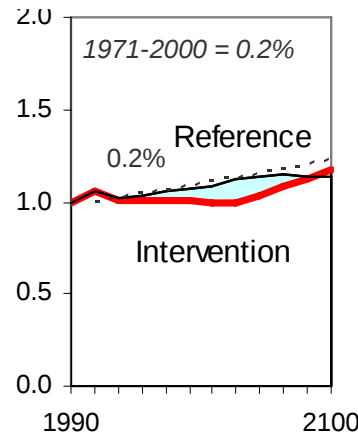
GDP
P

**Energy Intensity of
Economic Activity**



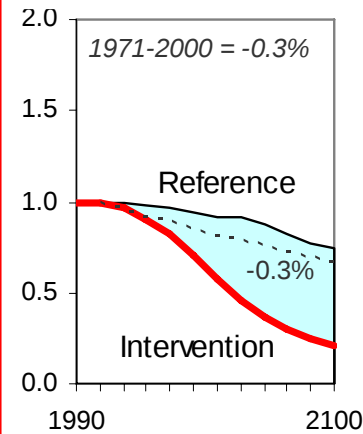
FE
GDP

**Energy Supply
Loss Factor**



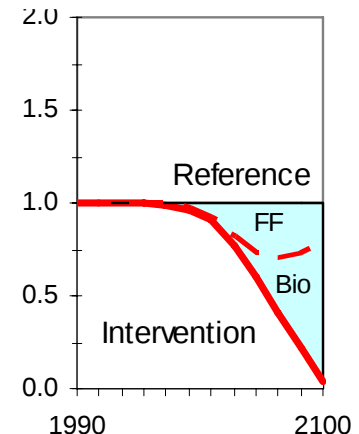
PE
FE

**Carbon Intensity
of Energy Supply**



TC
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**Fraction
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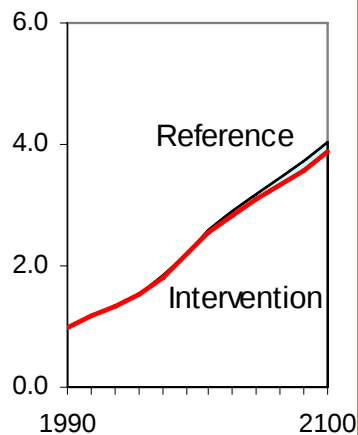
C
TC

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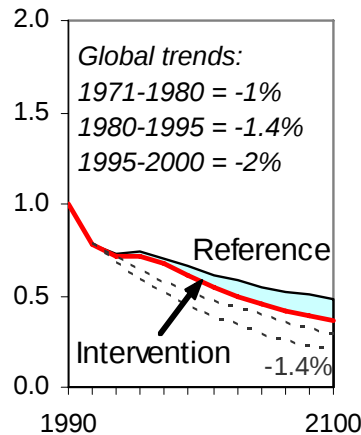
Examining the Role of Efficiency

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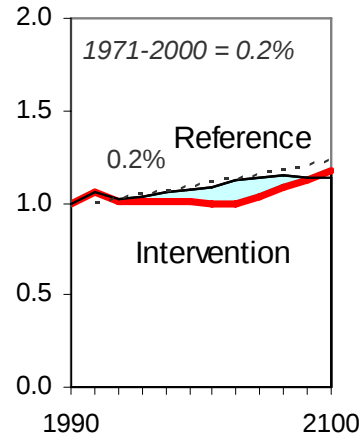
$$\frac{\text{GDP}}{P}$$

**Energy Intensity of
Economic Activity**



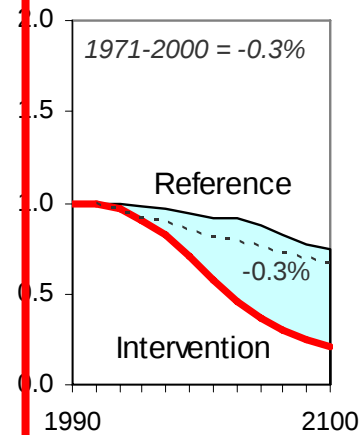
$$\frac{\text{FE}}{\text{GDP}}$$

**Energy Supply
Loss Factor**



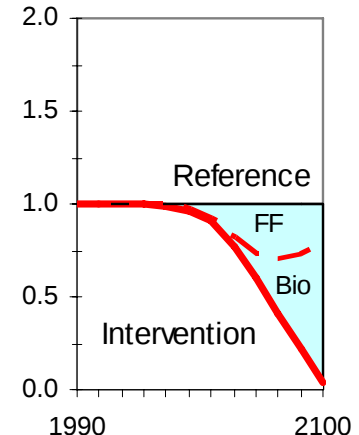
$$\frac{\text{PE}}{\text{FE}}$$

**Carbon Intensity
of Energy Supply**



$$\frac{\text{TC}}{\text{PE}}$$

**Fraction
Disposed
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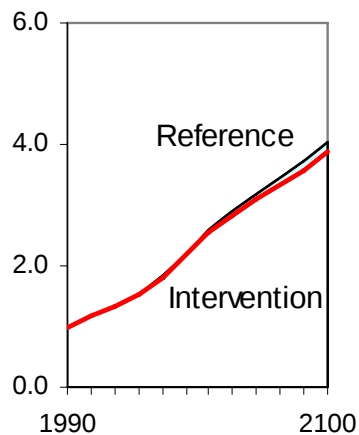
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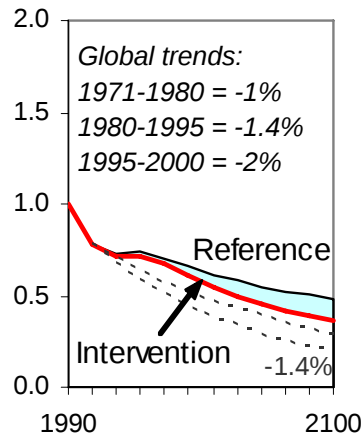
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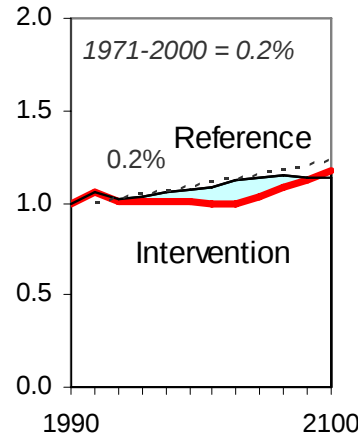
GDP
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**Energy Intensity of
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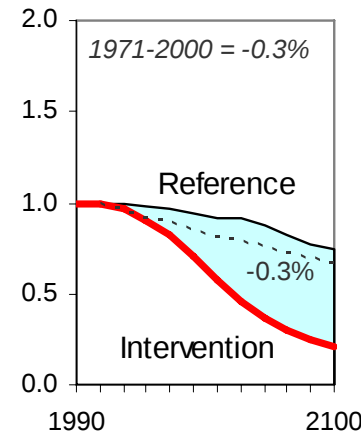
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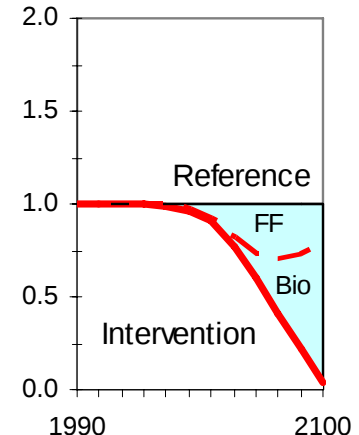


PE
FE

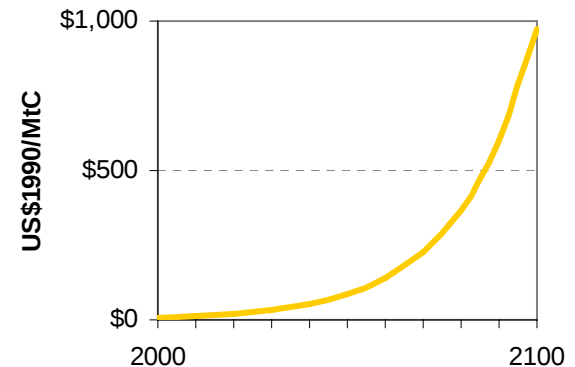
**Carbon Intensity
of Energy Supply**



**Fraction
Disposed
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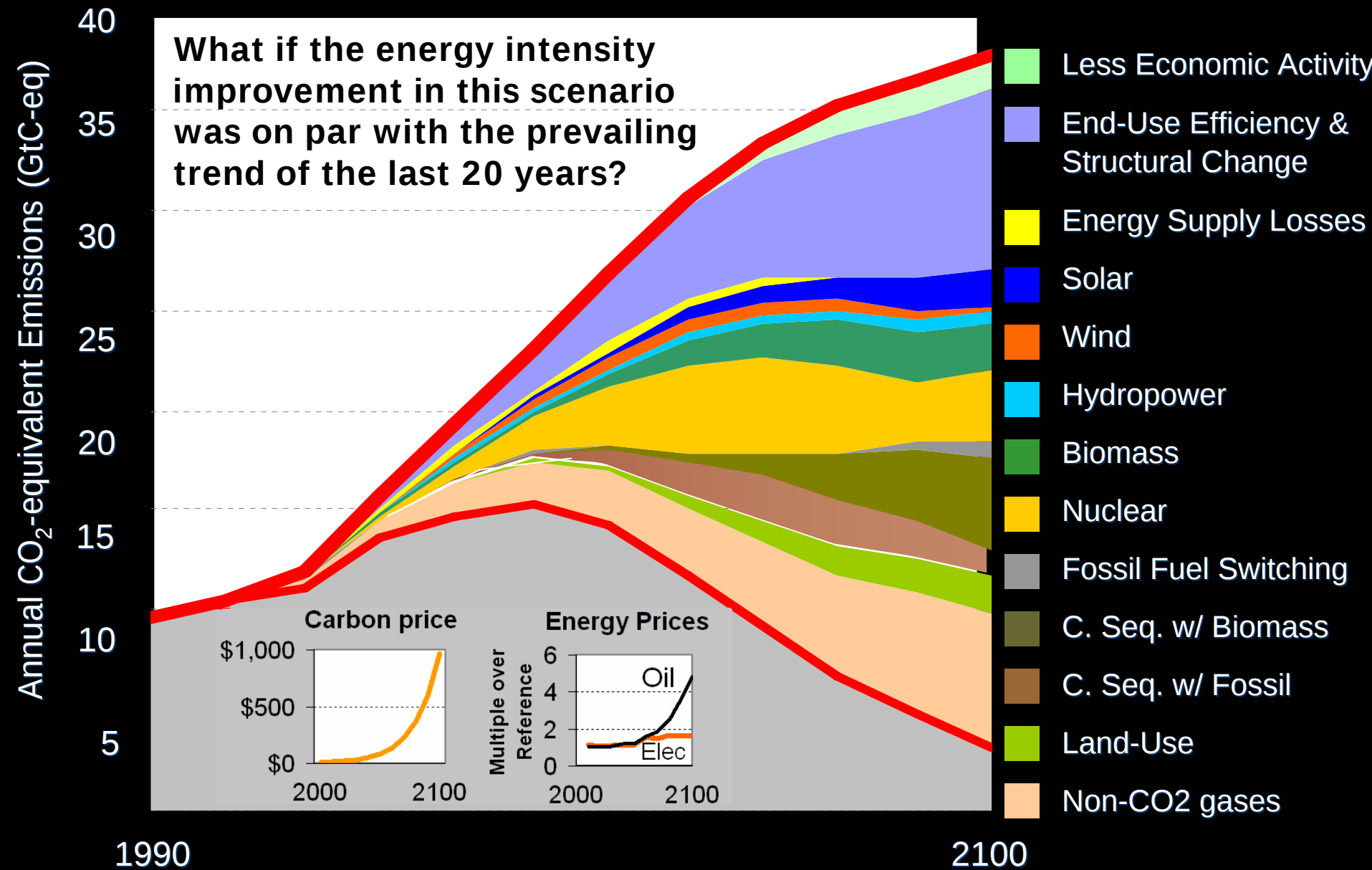
Carbon Shadow Price



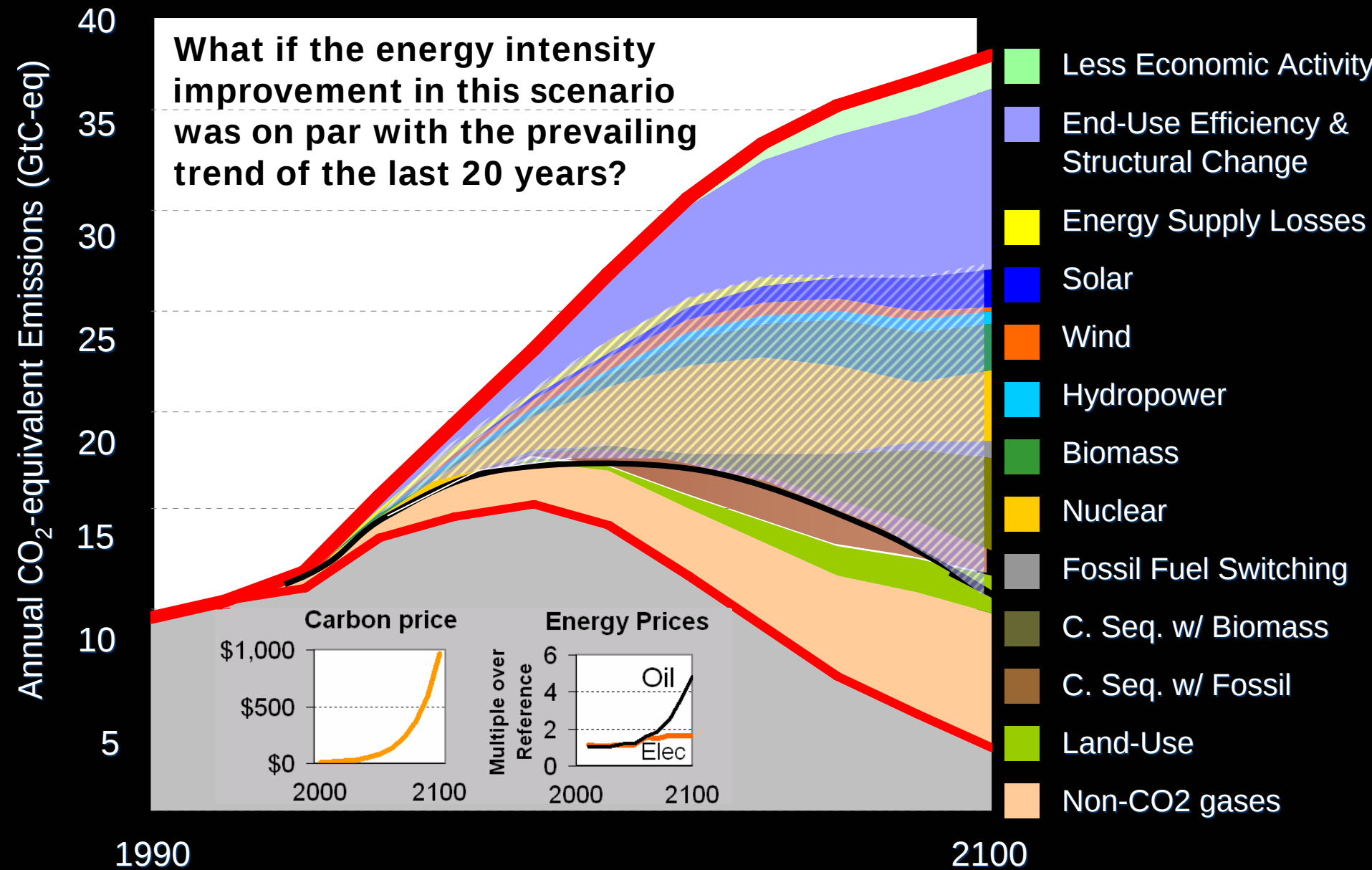
What if...?

Indexed to 1990=1

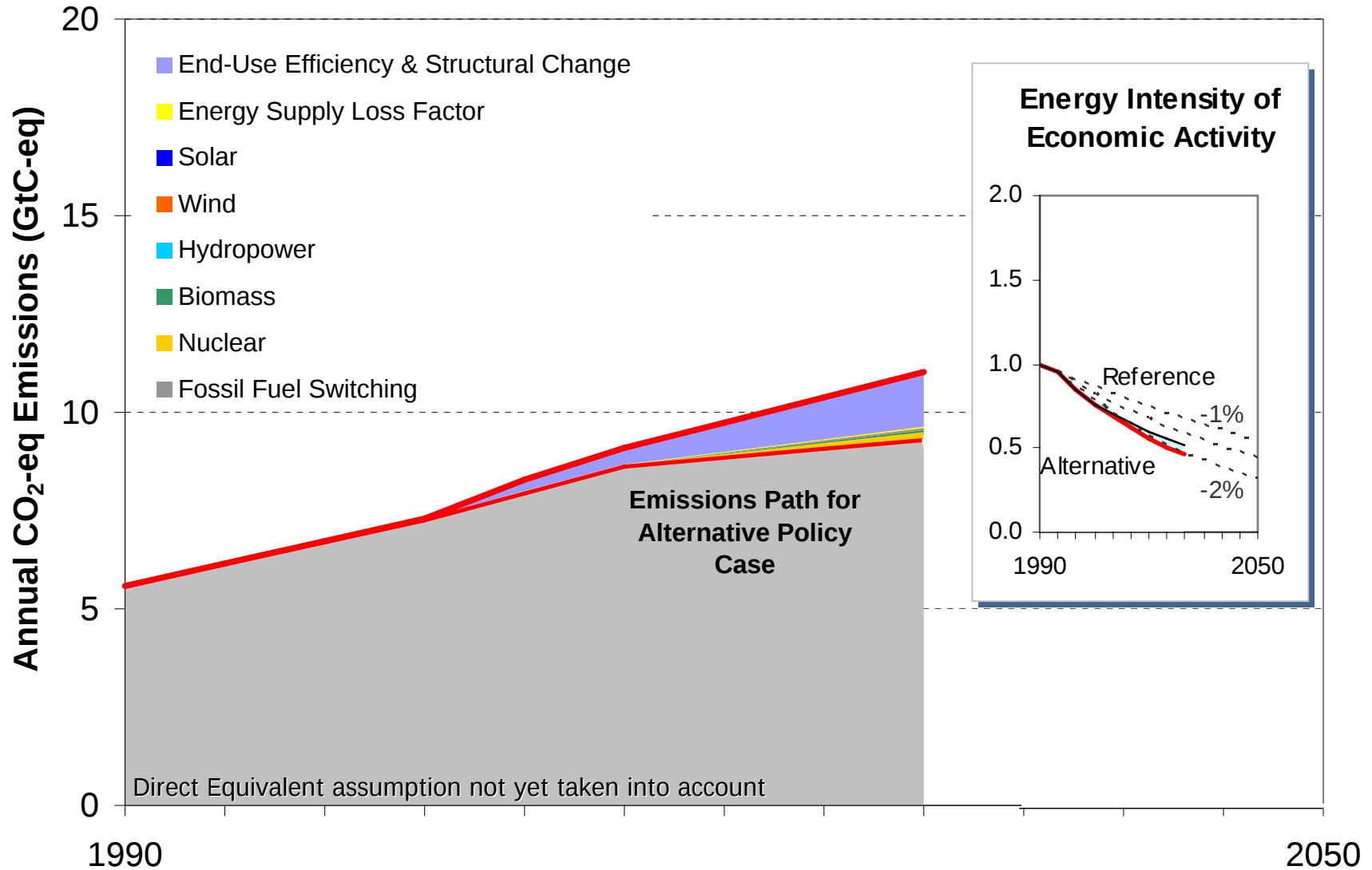
What difference does 0.5% make?



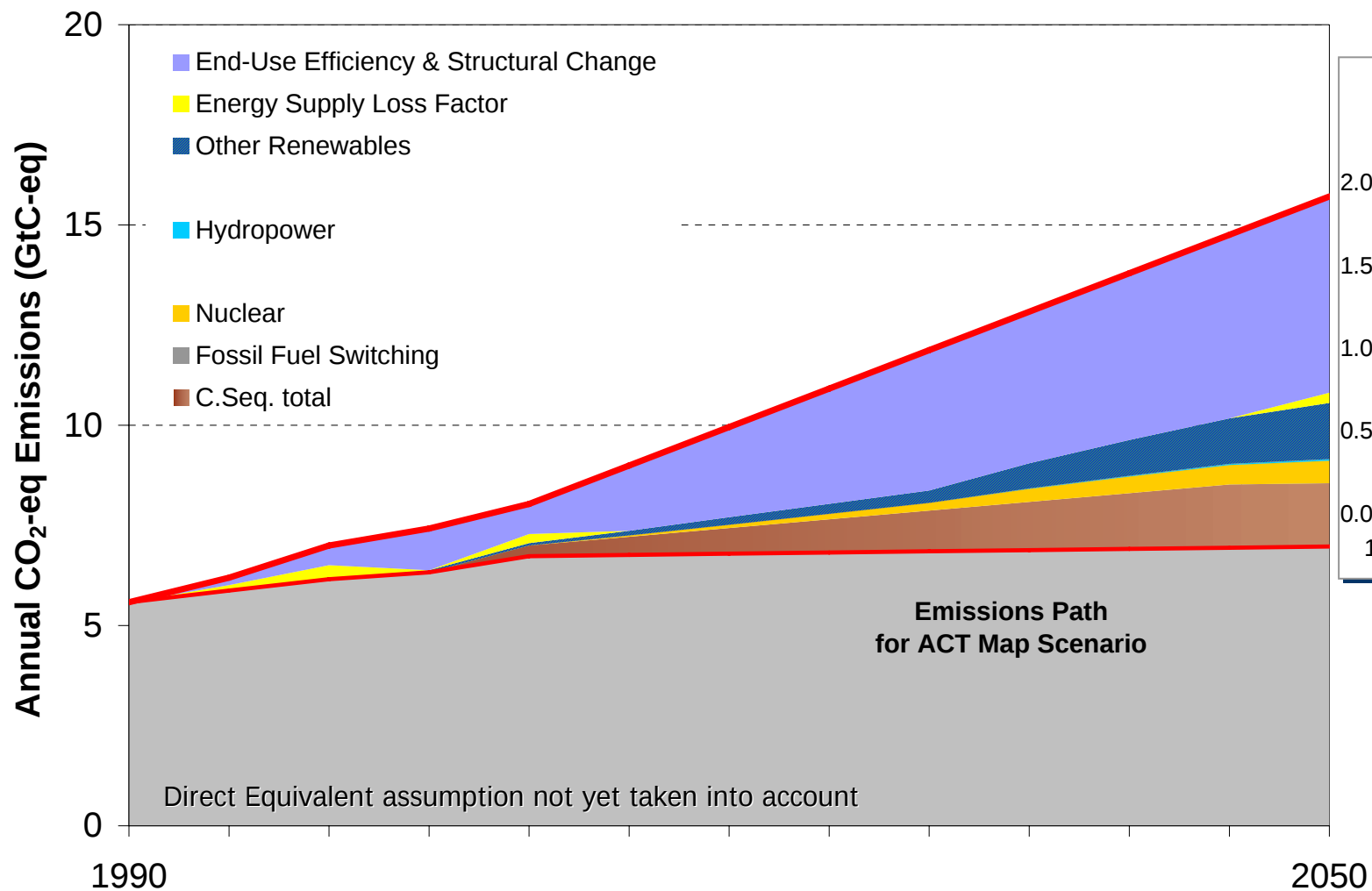
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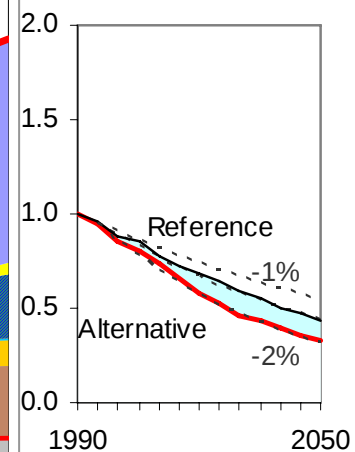
IEA WEO 2006 Reference & Alternative Policy Case



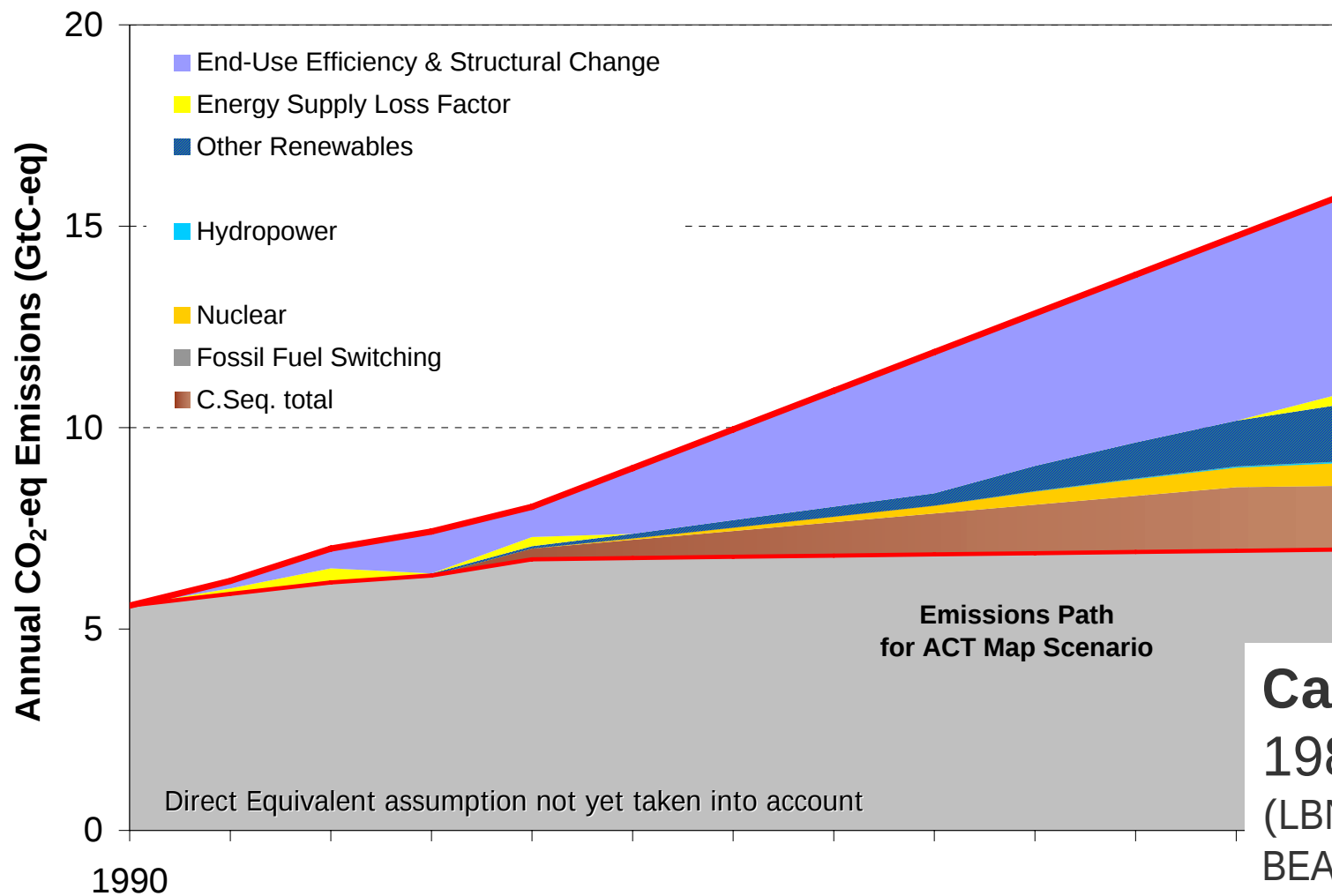
IEA Energy Technology Perspectives: WEO 2005 & "Map"



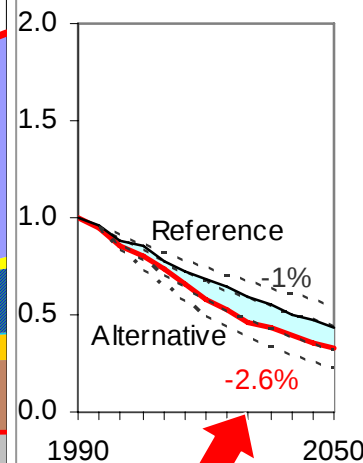
Energy Intensity of Economic Activity



IEA Energy Technology Perspectives: WEO 2005 & "Map"

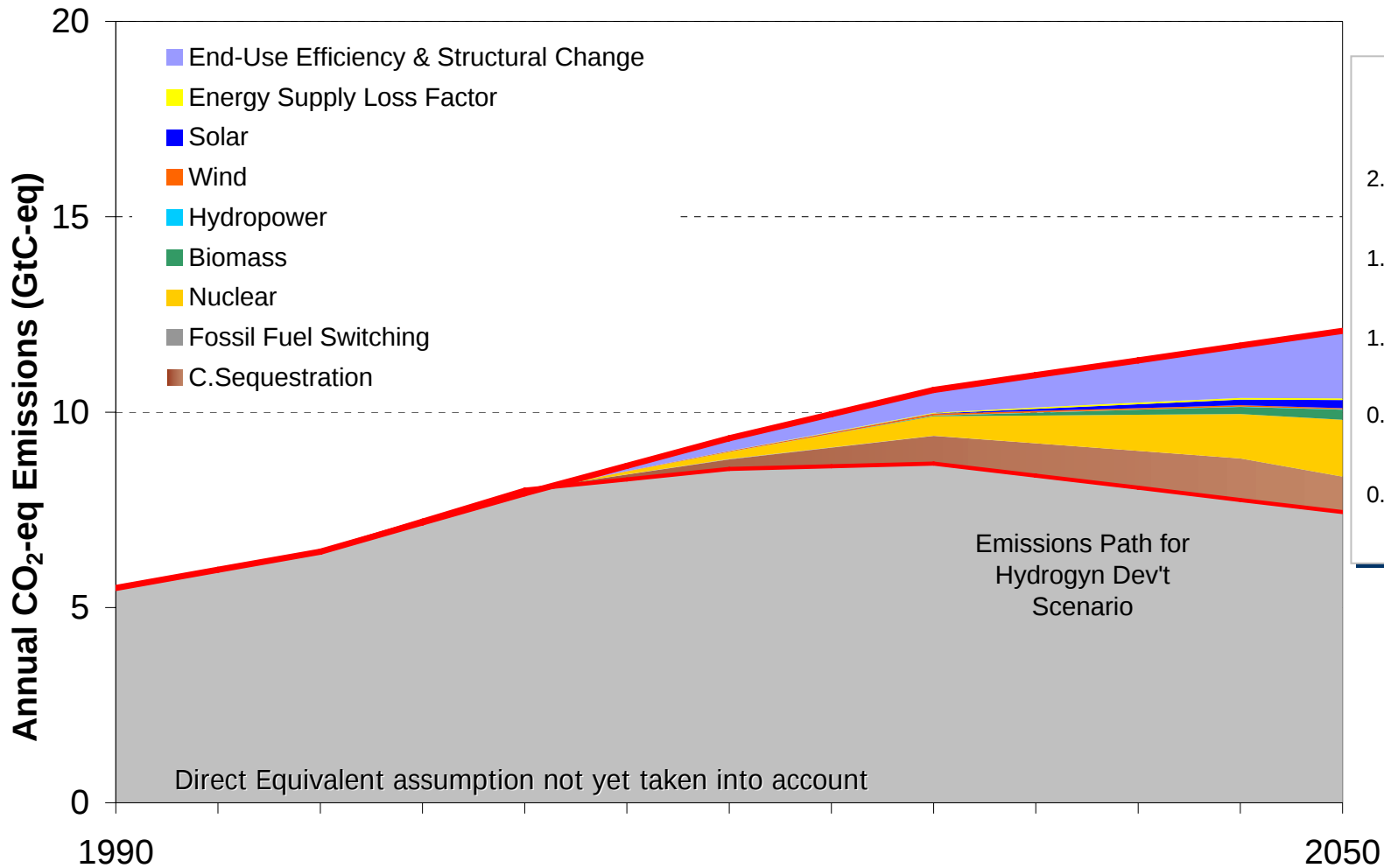


Energy Intensity of Economic Activity

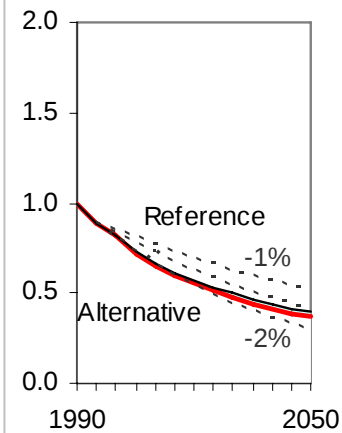


California
1980-1996
(LBNL data from
BEA and EIA)

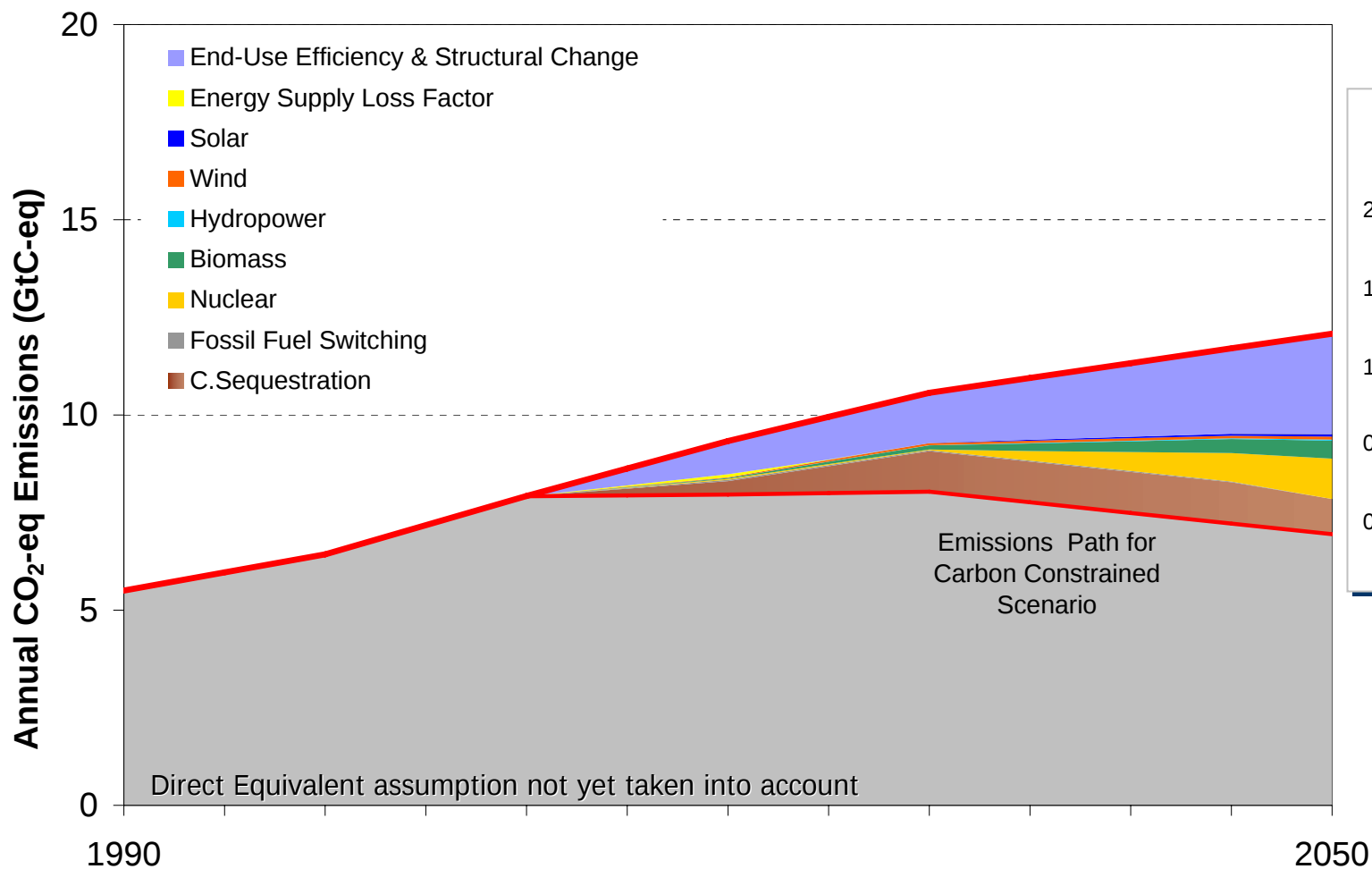
World Energy Technology Outlook: Baseline & H2 Dev't



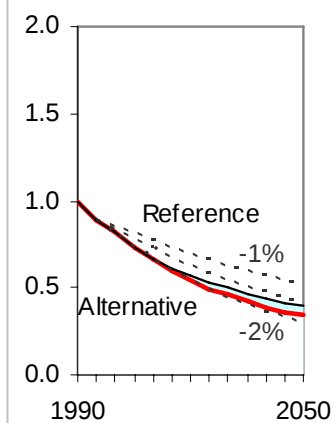
Energy Intensity of Economic Activity



World Energy Technology Outlook: Baseline & Carbon Constraint



Energy Intensity of Economic Activity



Exploring Energy Futures

- Scenario analysis for high-stakes futures
- Constructing a common framework for interpretation
 - How do policy interventions affect key drivers of emissions?
 - What are the sources of mitigation in stabilization scenarios?
- Insights from analyzing several widely-cited energy scenarios
- What is the role of energy efficiency?
- Summary of Findings, and questions of your curiosity!

Summary of Findings

- When sufficient data is disclosed, **two decomposition techniques can be applied to a wide range of energy scenarios** to perform initial validation and assessment of diverse energy futures from a variety of sources.
- Application of these techniques indicate that the **contribution of energy efficiency is often understated**, straining energy supply options and leading scenarios to deploy high-risk technologies on a large scale.
- Even with aggressive investments in efficiency, **the level of effort implied by stabilization scenarios is staggering**.
- **Research investments in pre-commercial opportunities for efficiency improvements are vital** at the device, system, and structural levels.
- For the vast majority of graduates who become decision-makers beyond academia, **investment in *courses* on energy efficiency is essential**.
- **We are all decision-makers in a “choose your own adventure” world.**

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